JULY 1985 VOL. 7 NO. 7

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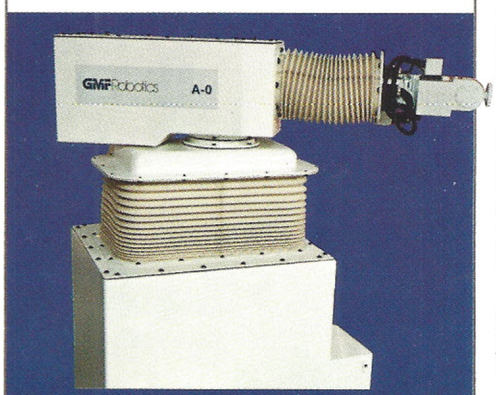
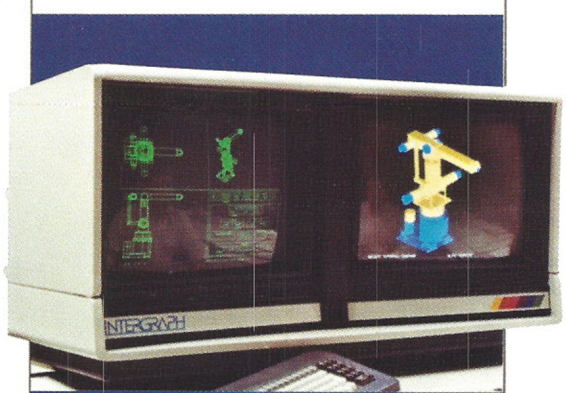


GMF clean room robot.



CAD/CAM off-line programming system.

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ROBOTICS AGE™

THE JOURNAL OF INTELLIGENT MACHINES

JULY 1985 VOL. 7 NO. 7

EDITORIAL

FEATURES

DEPARTMENTS

About the cover: This month's cover, supplied by Adaptive Intelligence Corp., shows the Adaptive Assembly Robotic Machine assembling an 8-inch Winchester hard disk system. The gripper, on the right, has four sensors with which it determines the precise position of the spindle onto which the disks are to be placed. (See related article on page 10.)

Editorial

Sensors and Robotics

BY CARL HELMERS

Even before Isaac Asimov's novel, *I, Robot*, was published in 1939, science fiction readers had become very enthusiastic about the prospects of having intelligent, friendly robots as their helpers. Asimov, with his three laws of robotics, codified the ethics of the human-robot interaction in an imagined future. Not only would Asimov's robots never harm a human, they would actually prevent anyone or anything else from harming one. Their own safety came last. A whole series of science fiction works was derived from the problems of interpreting and applying these central dicta of Asimov's robotic ethics to imagined real-world situations.

Compared with Asimov's ideal robots, today's robotic systems are indeed stodgy, if not downright stupid. But change the basis of comparison to most conventional machines and our present attempts to engineer intelligent machines look much better. Robotic systems and other computerized real-world products of mankind are beginning to offer some hope of intelligence, although nowhere near the sensory sophistication and quasi-human qualities of Asimov's robots with their positronic brains. The glimmer of intelligence in modern systems comes from a combination of three key technologies: microprocessors, computer software, and sensors.

An *intelligently designed* machine might not have a computer, but without a computer there can be no *intelligent machine*. An intelligent machine is a combination of computer technology with sensors and other technologies. This combination may perform an old function better or, in some cases, accomplish something formerly impossible for a machine, such as moving around autonomously.

Autonomous robots use sensors for navigation. They are beginning to use microprocessors and software in ways other than simple replication of memorized patterns. We've recently seen quite adequate demonstration that robots like the Arctec Gemini can use inexpensive sensors of various sorts combined with cleverness in software to find their way about. At present, such experiments in product design are slow in accomplishing "elementary" (to those who don't understand the problem) acts like going from one room to the next. Still, the several minutes Gemini needs to change rooms beats the SRI Shakey robot's performance of a decade ago, using a roomful of computer equipment which would now be called a "superminicomputer." Gemini accomplishes its goal-seeking autonomous activities with the aid of a CMOS on-board microcomputer or three and an array of crude but inexpensive sensors.

Industrial robotic systems are beginning to reflect similar sensory sophistication. We see vision systems used for quality control inspection and occasionally for guiding operations. Sensors are becoming an assumed part of the more productive manufacturing applications of intelligent systems, systems that extend far beyond the bounds of a common but restrictive definition of a robot as a mere reprogrammable manipulator mechanism.

Another primary concern in industrial robotics is making inviolable the work envelope of stationary or mobile manipulation systems when the power is on. Accidents can and will occur if human beings occupy the same physical space as high-powered machinery components. Safety can sometimes be accomplished by barriers and interlocks. But the foolish love to try to outwit such measures. Intelligent machines with advanced and cleverly designed sensor subsystems provide a more complete form of protection of human from machine—and occasionally machine from human. Integrating today's smart sensors into today's not-so-bright robots can bring about a fair approximation of Asimov's first law, the rule stating that "A robot must not injure a human being, or, through inaction, allow a human to come to harm." ■

Excerpted in part from an address given to the IEEE Boston Section Robotics Chapter, 22 May 1985.

Calendar

JULY

8–12 July. Robot Manipulators, Computer Vision, and Automated Assembly. Massachusetts Institute of Technology, Cambridge, MA. Contact: Director of the Summer Session, Room E19-356, Massachusetts Institute of Technology, Cambridge, MA 02139, telephone (617) 253-5863.

This short course in industrial robotics is being offered under the auspices of MIT's Artificial Intelligence Laboratory. The 57 topics to be covered fall under the general headings of robot manipulators, computer vision, automated assembly, applications, and systems components. The emphasis of the course will be on developing strategies for the solution of problems in sensing, spatial reasoning, and manipulation.

15–17 July. 12th Annual Symposium of the Association for Unmanned Vehicle Systems. Anaheim Marriott Hotel, Anaheim, CA. Contact: John Ganoe, AUVS Executive Director, 1133 Fifteenth St. N.W., Washington, DC 20005, telephone (202) 429-9440.

The symposium will address such topics as applications and operations, cost effectiveness, vehicles and systems, avionics and navigation, command and control/programming, sensors and payloads, and robotics and AI. There will also be an exhibit.

17 July. iRUG Annual International Conference. Palmer House, Chicago, IL. Contact: Catherine R. Moon, iRUG Coordinator, MS/HF2-57, 5200 N.E. Elam Young Parkway, Hillsboro, OR 97123, telephone (503) 640-7038.

"The Future Direction of Real-Time Software Applications" is the theme of this conference for iRUG, the iRMX Users' Group. Application and technical presentations will be made by iRUG members and independent software vendors, and the INTEL Corporation will preview the iRMX 286 Operating System. A demonstration room will provide hands-on experience with the new system and other real-time software.

29 July–2 August. Computer Vision and Image Processing. University of Michigan, Ann Arbor, MI. Contact: Engineering Summer Conferences, 200 Chrysler Center, North Campus, the University of Michigan, Ann Arbor, MI 48109, telephone (313) 764-8490.

With the advent of high-speed computers, processing and extracting information from images has become an important technology. This course is designed to present techniques for processing images and recovering useful information, with emphasis on solving problems that have a variety of applications.

AUGUST

19–20 August. Developing End-of-Arm Tooling for Industrial Robots. Norcross (Atlanta), Georgia. Contact: Diane Korona, Program Administrator, Robotics International of SME, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 392.

This workshop, worth 12 professional credits toward the SME recertification program, will focus on end effectors and will cover analysis of part, process, and robot; productivity; and design techniques. Also to be addressed are type of power to be used, floor layout and work envelope size, part configuration, cycle time, and robot characteristics. The conference will be held again on 22–23 October at the Boston Park Plaza Hotel, Boston, MA.

20–22 August. International Conference on Production Research. University of Stuttgart, Stuttgart, West Germany. Contact: ICPR Secretary, c/o IPA/IAO, Nobelstrasse 12, 7000 Stuttgart 80, Germany.

The objectives of this conference are to support the international exchange of experience about outstanding industrial developments and the latest results of production research. Robots and sensors, computer-aided design and computer-aided manufacturing, assembly automation, and production planning and control are some of the conference topics to be discussed.

21–22 August. Applying Sensors in Robot Applications. Norcross (Atlanta), GA. Contact: Diane Korona, Program Administrator, Robotics International of SME, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 392.

Highlights of this conference will include sensor types and functions, sensor selection techniques, interfacing sensors to system components, and designing sensors into tooling. The course is worth 12 credits toward the SME recertification program.

SEPTEMBER

4–6 September. ORCAL '85 Expo. Anaheim Convention Center, Anaheim, CA. Contact: Public Relations Dept., Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0777, or Public Relations Dept., American Society for Metals, Metals Park, OH 44073, telephone (216) 338-5151.

The Orange County Manufacturing and Metalworking Conference and Exposition, ORCAL, will feature sessions on composites, robotics, flexible manufacturing systems, machine vision, and electronics in manufacturing. Demonstrated at the exposition will be computer-run manufacturing systems and processes, quality control and inspection devices, computerized design equipment, precision machining technologies, and automated inventory / warehousing equipment. The American Machine Tool Distributors' Association will participate for the first time.

6–8 September. International Personal Robot Congress & Exposition. Moscone Center, San Francisco, CA. Contact: Sharon D. Smith, Chair, IPRC '85 Organizing Committee, 8822 S. Martin Lane, Conifer, CO 80433, telephone (303) 674-5650.

The second annual IPRC, expected by the organizers to attract over 2500 personal robot enthusiasts, will feature seminars on personal robot software and hardware, human services, robots in space, the business of personal robots, and personal robots in education. There will also be an exhibit by leading commercial manufacturers of personal robots, sensors, and related equipment. In addition, there will be displays by personal robot developers who have created their own robots in workshops and garages.

9–10 September. Second International Conference on Advanced Robotics. Keidanren Kaikan Bldg., Tokyo, Japan. Contact: Mr. A. Yasutake, Organizing Secretary, Japan Industrial Robot Association, Kikai Shinko Kaikan Bldg., 3-5-8, Shibakoen, Minato-ku, Tokyo, 105 Japan.

The primary objective of this conference is to provide an international exchange of information on intelligent, mobile, and sensory control robots. Approximately 70 papers will be presented on topics such as the mechanics of locomotive robots, the mechanics of manipulators, sensory systems, intelligent manipulation and location, robots for unstructured environments, and the results of national projects.

10–12 September. Midcon/85. Chicago, IL. Contact: Nancy Hogan, Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, CA 90045, telephone (213) 772-2965.

Directed toward practicing technologists, the Midcon/85 conference will address practical applications or updates of the state of the art of electronics, emphasizing current or near-term advances, trends, and applications of electronic technology and product manufacture.

Calendar

Among topics to be covered are communications and networks, electronic/microelectronic packaging, image processing and pattern recognition, speech processing, office automation, and artificial intelligence.

11–13 September. Fifteenth International Symposium on Industrial Robots. Keidanren Kaikan Bldg., Tokyo, Japan. Contact: Mr. Y. Komori, Organizing Secretary, 15th ISIR, Japan Industrial Robot Association, Kikai Shinko Kaikan Bldg., 3-5-8, Shibakoen, Minato-ku, Tokyo, 105, Japan.

More than 100 papers will be presented on the latest research, developments, applications, and socio-economic evaluation of industrial robots during this symposium. In addition, an international exhibition of industrial robots and their applied systems equipment will be held September 12 through 16 at the exhibition hall of the International Trade Fair Center, Harumi, Tokyo. After the symposium, a study tour during which participants may visit Japanese robot manufacturers, users, and research laboratories is also being planned.

23–25 September. Space Tech '85. Disneyland Hotel Convention Center, Anaheim, CA. Contact: Gregg Balko, Technical Activities Dept., Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 368.

Sponsored by nine technical and engineering societies, SPACE TECH '85 will focus on the engineering technologies and solutions required to make space industrialization practical and economical. There will be sessions discussing artificial intelligence and robotics; guidance, controls, and sensors; materials processing and applications; simulation and software; composites; space structures; habitation; propulsion; and manufacturing in space.

The accompanying exposition will feature demonstrations of the technologies, products, and services used by space industries in various space programs worldwide. Such exhibits will include robotics, sensors and controls, advanced materials, CAD/CAM systems, and scores of other high technology products related to space industrialization.

OCTOBER

8–10 October. International Robot Conference and Exhibition. Philadelphia Civic Center, Philadelphia, PA. Contact: Tower Conference Management Co., 331 W. Wesley St., Wheaton, IL 60187, telephone (312) 668-8100.

Twenty-one technical sessions and two tutorial courses will be offered at InteRobot East '85, intended to cover technological advances, new developments, and system refinements affecting the robotics industry. Concurrent and at the same location will be an exhibition of robots and robotic systems, sensors, AI hardware/software, machine vision, and material handling equipment.

9–11 October. Robots East. Bayside Exposition Center, Boston, MA. Contact: Jeff Burnstein, PR Manager, Robotic Industries Association, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-7800.

This new robotics show will feature product demonstrations by robot manufacturers and accessory equipment suppliers. A technical conference will accompany the exposition. The RIA is the only trade association in North America organized specifically to serve the field of robotics. Its more than 320 company members include robot manufacturers, distributors, accessory equipment and systems suppliers, users, consultants, and research organizations.

15–17 October. Developing Robot Workcells. Norcross (Atlanta), GA. Contact: Diane Korona, Program Administrator, SME Special Pro-

Calendar

grams Dept., One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 390.

This workshop will feature discussions of parts presentation, end effectors, sensing, gauging, equipment relocation, and robot workcell design considerations. Laboratory sessions will be combined with technical lectures to enable conferees to learn how robotic elements function within a variety of workcells. The course, worth 18 credits toward SME recertification, will be repeated on 10–12 December in Atlanta.

21–24 October. ISA/85 COMPUTEC. Philadelphia, PA. Contact: Fred E. Gore, Fisher Controls International, Inc., 8301 Cameron Rd., Austin, TX 78753, telephone (512) 834-7066.

ISA/85 conference sessions will include man/machine interfaces, microprocessor systems design and application, computerized batch processing, and personal computers applied to control system functions and improvement.

NOVEMBER

4–7 November. AUTOFACT '85 Conference and Exposition. Cobo Hall, Detroit, MI. Contact: Tom Akas, Group Manager, Public Relations, Computer and Automated Systems Association/SME, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500.

AUTOFACT '85 will feature four days of technical sessions, forums, and an exposition focusing on the latest advances in the technologies and equipment of computer-integrated manufacturing. Some of the topics to be discussed include database management, local area networks, ICAM's factory of the future, artificial intelligence, expert systems, group technology, process planning, and simulation and modeling.

A manufacturing automation protocol project sponsored by General Motors Corporation and Boeing Computer Services will demonstrate manufacturing communications technology implemented by various vendors linking a factory floor local area network to a front office local area network.

Letter

I thought the article in the May issue of *Robotics Age* on the Compliant Mechanical Gripper which I co-authored with Dr. Parkin looked very good in its final form. However, I would like to make two corrections if I may.

First, M.I.T. Lincoln Laboratory is not located on campus in Cambridge, MA. The correct address is 244 Wood St., Lexington, MA 02173.

Second, the research was done as a lab project for a graduate level night school course at the University of Lowell. Neither M.I.T. Cambridge nor M.I.T. Lincoln played any part in the development of the end effector.

Sincerely,
Warren K. Hutchinson
244 Wood St.
Lexington, MA 02173

Correction

Our particularly thorough readers probably have a few questions about the "About the cover" information on Page 1 of the June *Robotics Age*. What we published was a description of another photo from the same company. We caught our mistake at the last minute, corrected the copy, but forgot to advise our printer of the change. Here is the correct version: This month's cover, supplied by Adept Technology, Inc., shows AdeptMicrovision™ inserting a ceramic In-line Package into a through-hole circuit board.

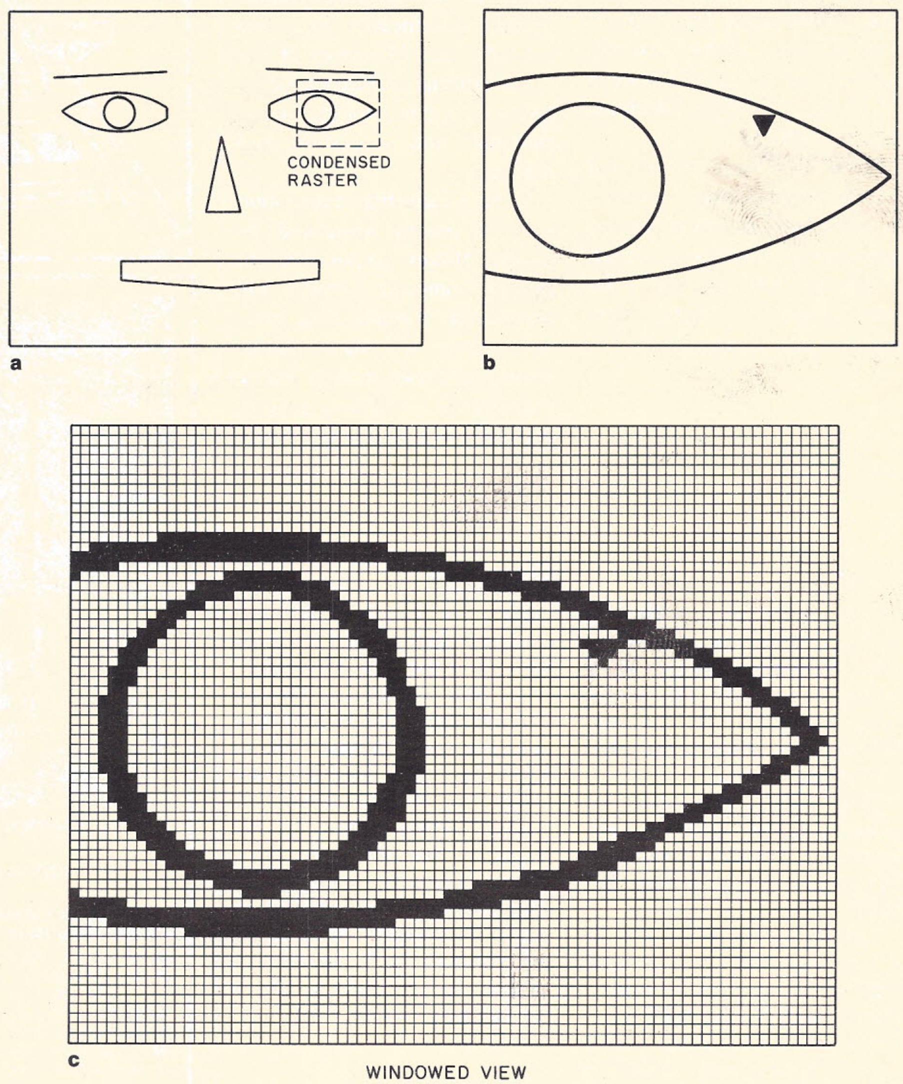
A NEW SUPER CAMERA FOR VISION SYSTEMS

Jim Green
Key Image Systems, Inc.
20100 Plummer St.
Chatsworth, CA 91311

Almost all vision system manufacturers use television cameras as sensors. These produce images pleasant to the eye, but unsuitable for the computer. The cameras are cheap and readily available, however, so they find wide use and the industry has learned to accommodate itself to them. A great deal of work has gone into special hardware and software whose only purpose is to compensate for camera inadequacies such as insufficient resolution, excess noise, rigid field of view, inflexible aspect ratio, spot-dependent gain and black level, and rigid orientation. It has always seemed easier to work on the lighting, parts-handling, video processor, and software than to make a proper camera. The result has been that piece by piece, far more has been spent on accommodation than on correction.

Most of these cameras (surveillance, studio, infrared, low-light, CCD, CID, etc.) are configured to give a picture that fits the standard RS170 format—60 frames per second, interlaced, 500-line raster, etc. A use limitation is imposed by the large base of installed and available video equipment. There is no point, for example, in buying a higher-resolution camera if one cannot use it with a stock monitor. In fact, TV cameras are inherently capable of much higher resolutions, but this capability is deliberately thrown away for the aforesaid reasons. The electron-beam spot size, and the video bandwidth are sufficient to give only about 500 lines, and, in most cameras, even this is degraded by rolloff in the video amplifiers.

The 60 Hz frame rate is also single-purpose. It is convenient to use the power-line frequency because it is already there, and because line-generated noise doesn't bother the viewer too much. The common raster generators are oscillators, synchronized by the power line, and, as a by-product, they generate the high voltages needed for electron beam control. There is no need for, and therefore no attempt to achieve precision. Thus, the displayed images are only accurate enough to look acceptable; they have little uniformity from product to product—and they don't pre-



Figures 1a,b,c. In the Rotazoom approach to viewing portions of a scene (a), a condensed raster is used to scan a portion of the image presentation as at (b). The condensed raster covers a smaller area, so the number of pixels in the expanded view is the same as if the entire scene were viewed, giving more information. The corresponding windowed view (c) simply takes a subset of the full screen pixels and expands them.

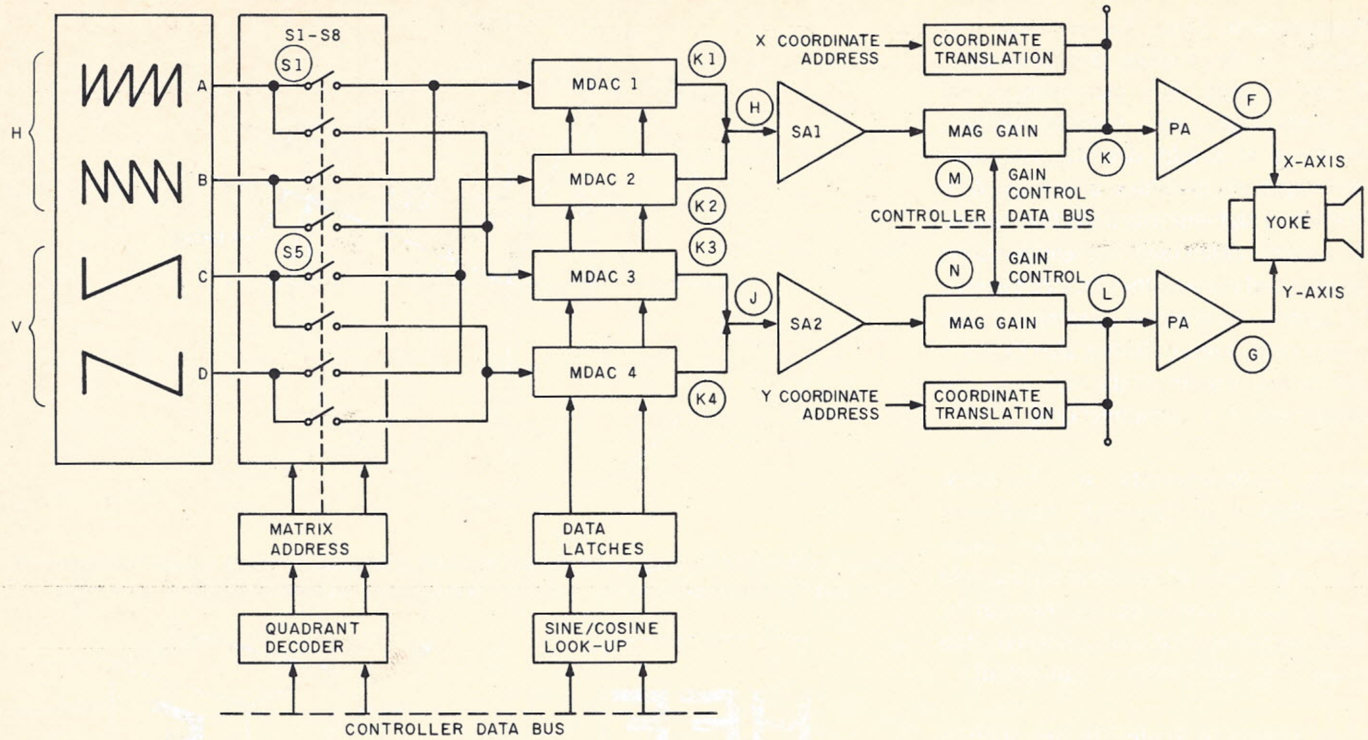


Figure 2. Block diagram of Rotazoom camera hardware. The camera electronics changes the region of scanning according to digital commands presented on its controller bus.

tend to have any. The eye tolerates these dimensional distortions.

The eye also has a narrow field of view, and a much sharper visual acuity at its center than at its periphery. To accommodate this acuity, TV cameras have at their centers enhanced resolution and sensitivity. This means the video voltage levels are different in different portions of the raster. Much work has been done in vision systems to reduce the effects of these variables.

The raster itself is also a problem for vision system use. Aside from its non-uniformity and nonlinearity, it is inflexible, having only one size, dimension, direction, and aspect ratio. (There are solid-state cameras which selectively correct certain of these problems as a part of a tradeoff). A proper camera, designed for the machine instead of for the eye, avoids these inadequacies and can give a vision system some dramatic performance features. We call our proper camera the Rotazoom™.

First, the enhanced camera can scan at any angle, so the problem of object orientation is removed. Tilted labels, skewed marks, and misaligned parts are seen as if they were level and flat. This is true also of rolling and spinning objects. The camera "derotates" and stops at any position. Another dramatic effect is an electronic zoom (Ezoom) which allows the machine to select a small detail and enlarge it. The effect is similar to instant optical zoom. Also possible are the rectifying, or "rubber sheeting" functions, used to remove the distortions of curved or tilted surfaces.

Such flexibility is made possible by software control of the camera raster. Its position, size, shape, and direction are determined by computer command. The effect is that of changing the lens and repositioning the camera every few milliseconds.

In order to freely use these features, some basic camera deficiencies must be removed by redesign:

- The response must be uniform, so the camera is as sensitive at the edges as at the center.
- The resolution must be higher and more uniform so small details in the corners can be zoomed in on.
- Beam-blanking and black-level control must be added and automatic gain control disabled to allow strobing.
- External sync (genlock) must be provided.
- Variable band-width video must be added.
- A special deflection yoke is needed.
- The deflection, acceleration, and focus must be redesigned to give sharp pinpoint spot size over the entire face (dynamic focus).

The enhancement of resolution is perhaps the most important feature. Most vision systems work with pattern edges, whose location and precision determine the system's usefulness. (One commercial system, in fact, deals exclusively with edges.) TV sets, especially those with color, do not require the sharpness necessary for edge-finding because the eye inserts an edge at the color boundaries. This is the reason color sets can use the same band width as black and white TV. An Ezoom camera can deliver the limit of available resolution by shrinking the whole raster to cover a small area of interest, but Ezooms are not requisites of the Rotazoom.

In Figure 1a, the left eye is of interest. The camera is mounted back where it can see the whole face. Then, without moving, it examines the left eye by scanning the eye area with a condensed raster (Figure 1a). Then the displayed view is shown as at Figure 1b. There is an analogous function in non-Ezoom systems called "windowing" where a part of the full view detail is merely excised (Figure 1c). The result is that only 70 or 80 of the 500 scan lines define the image in Figure 1c, whereas the whole 500 are used in Figure 1b. Windowed images are not useful for measurement.

Measurement. Since Ezoom adds considerably to the precision of edge location, it can be used as a measurement aid in both high- and medium-precision machines. As an edge detector, with precision stages, the usefulness is obvious. With its internal high-linearity deflection system, the camera, within itself, is a semi-precision gauging tool because the distance between the centers of any pair of condensed rasters is accurately known. Notice also that it is not necessary to orient the part, since the measurement is omnidirectional.

Extra Enhancements of Accuracy. Nonenhanced measurements in an Ezoom camera are expected to yield net resolution on the order of 1/3000 of the full field of view. Given more time, electromagnetic jitter, sweep mapping, and optical fiducials could yield still further enhancement.

Measurement of Angle. The first applications of the Rotazoom were for the correction of product position (derotation), and for correction of nonorthogonal (tilted) edges. However, tilt measurement is also possible. The technique is unconventional but obvious. The resolution is 0.35 degrees (360/1024).

Rubber Sheeting Functions. The above-described characteristics are available from wave forms and controls that are part of the camera. Some very interesting effects can be brought about by generating raster drive signals externally using the H and V amplifier terminals. Some examples are:

- Concentric arc-shaped rasters to read printing around an arc;
- Spirals to inspect the inside of a pipe;
- Trapezoids to reduce perspective effects;
- Variable-speed rectangles to reduce curved perspective effects.

THE ELECTRONIC SYSTEM

The camera system block diagram is shown in Figure 2. Horizontal (X) and vertical (Y) drives are shown at F and G. The basic drive waveforms are shown at A, B, C, and D. To produce a normal raster only A and C are used. If B or D is substituted, either the X or the Y axis is inverted. This allows images to be turned upside down, or left to right (mirror image), giving 90 degree rotation increments.

Rotation through other angles is more complex. A tilt of θ into quadrant 1, for example, requires that (cos A + sin C)

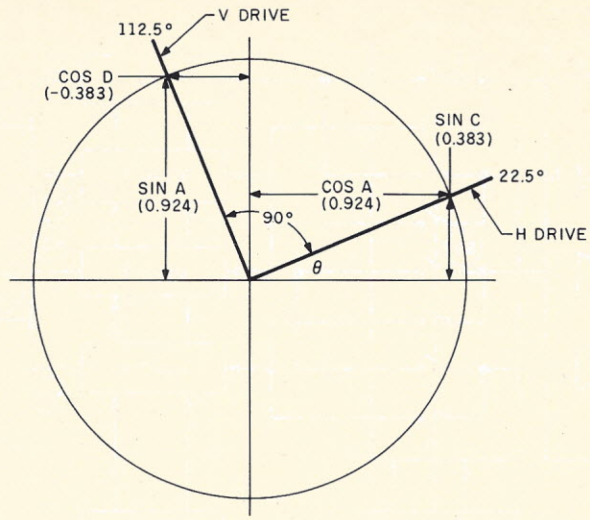
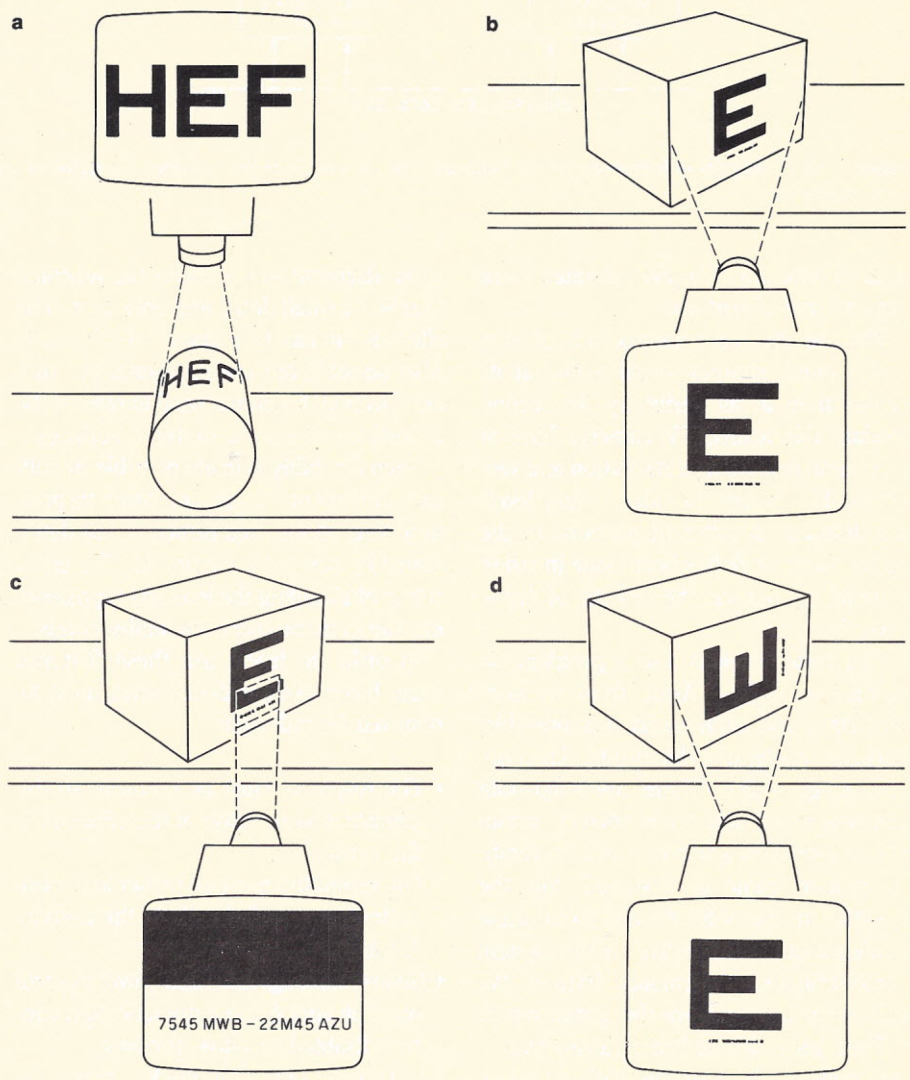


Figure 3. Rotation of the image about the line of sight is accomplished through a simple modification of the X and Y scan signals, using sine and cosine trigonometric functions identically on each signal.



Figures 4a,b,c,d. By Playing tricks with the X and Y functions used to drive the vidicon camera tube, various image corrections can be made. (a)A trigonometric variation in one image axis parallel to an object's axis of rotational symmetry can "unwrap" a curved label. This will work only for visible portions of the label. (b)A trapezoidal variation of the raster can be used to eliminate perspective effects. (c)Raster variations are independent of the electronic zoom technique. Thus, fine print on a portion of an image can be rectified and examined. (d)By using a trapezoidal scan plus switching the X and Y drivers, an image can be both rectified and rotated 90 degrees as in this example.

drive the H coil while (sin A + cos D) drives the V coil. The graphical derivation of these vector additions is shown in Figure 3, where $\theta = 22.5$ degrees. The H and V drives, displaced 90 degrees in space, are shown displaced 90 degrees in phase. The driving voltages are selected by S1 to S8. In this example, S1 and S5 are closed, and the signals are summed at junction H. The rest of the functions are obvious from the labels in the block diagram.

Raster size and shape are controlled by gain settings at M and N. Since the camera raster is always displayed as a full monitor view, a reduced camera scan is always zoomed up. Special design elements of the Rotazoom permit full use of this feature. The elements include smaller electron beam size, extra bandwidth, special noise treatment, etc. The achievable zoom is 5:1 without loss of detail. The effect is that of having a 2500-line camera, except that the full object must be seen as 25 separate zoom-up views.

Refer now to junctions K and L where the coordinate or position signals are summed. These provide a reference or center around which the raster is generated or rotated. This signal moves the camera raster to the precise center of interest. The change of position takes place during the frame-reset (blanking) period, so no time is wasted in panning. It is possible, using this technique, to see and read 60 individually viewed words per second. Rotation, translation, size, and aspect ratio are all shifted simultaneously. The words can therefore be in assorted locations, different sizes, and different orientations. This very convenient feature permits a one-type-size reader to recognize any size type without software change, and to adjust for tilted paper at the same time.

The waveforms generated within the Rotazoom can give only rectangular rasters. Some common inspection problems cannot be solved by such rasters, but these "rubber sheeting" applications might be addressed by producing special wave shapes in separate generators.

Figure 4a illustrates the classic curved label problem. If θ is not too large the image can be flattened. Figure 4b shows that a trapezoidal raster can be used to remove perspective. In Figure 4c, a trapezoid and Ezoom are used at the same time to read the fine print. In Figure 4d, trapezoid and rotation are combined.

One is struck by the similarity of camera evolution to that of the oscilloscope. Up to about 1950, oscilloscopes were useful only to look at waveforms. About that time, a small Oregon firm introduced enough stability and precision to turn the scope into a measuring device. In some respects, camera art is in much the same place today and it seems likely that the camera will follow the oscilloscope's path of development.

Jim Green is chairman of the board of directors and executive vice president of Key Image Systems, Inc.

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70	80	90
Excellent	Good	Fair

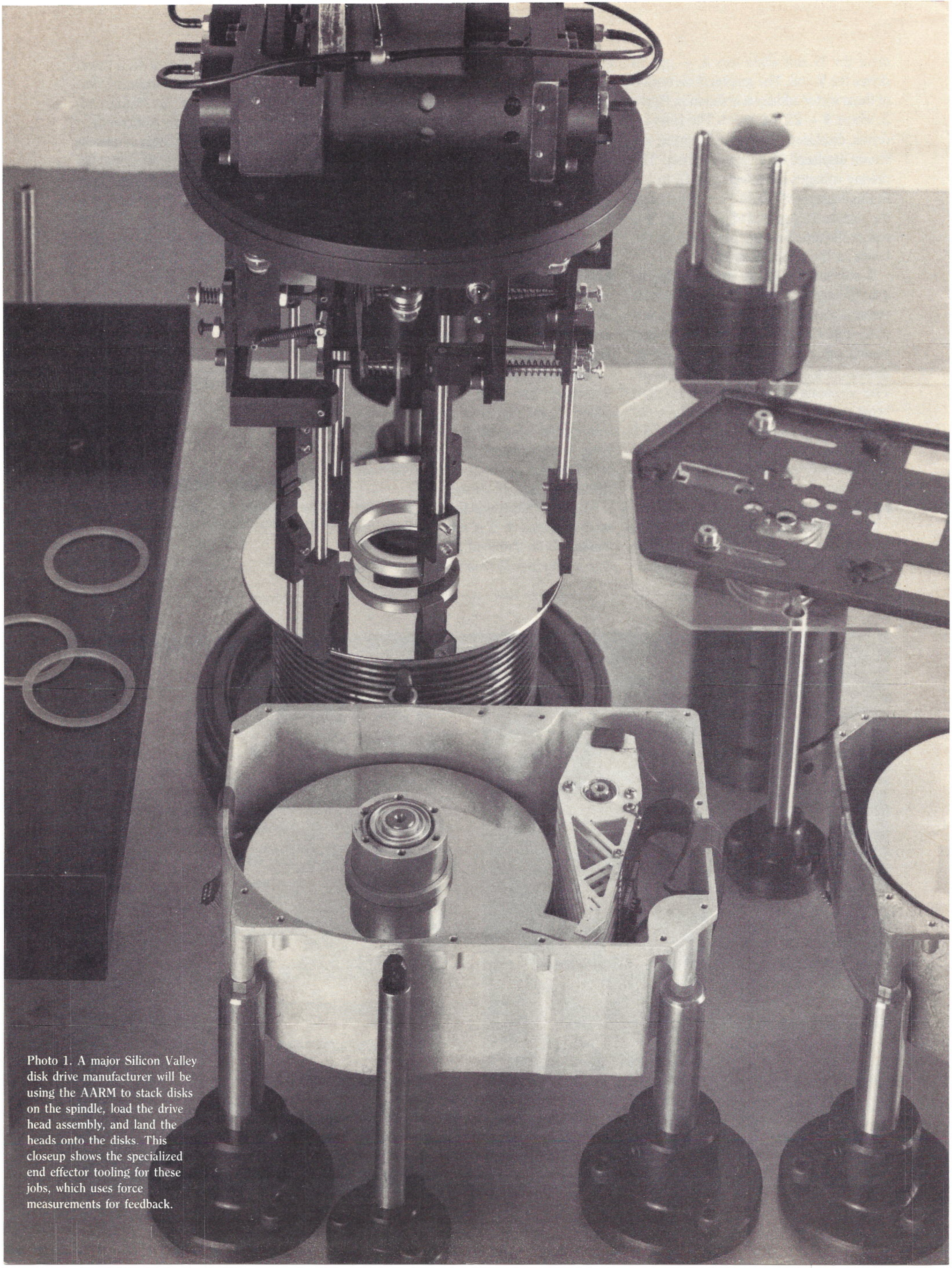

Photo 1. A major Silicon Valley disk drive manufacturer will be using the AARM to stack disks on the spindle, load the drive head assembly, and land the heads onto the disks. This closeup shows the specialized end effector tooling for these jobs, which uses force measurements for feedback.

FORCE SENSORS FOR ROBOTIC ASSEMBLY SYSTEMS

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Despite the current popularity of vision systems for robotic control, their effectiveness for precision assembly tasks has yet to be proved. At their present state of development, vision systems are affected by external factors, such as ambient or artificial light. They are used predominantly for two-dimensional primitive line and edge detection.

As an alternative to vision, tactile sensing has proven very responsive to precision and changing assembly requirements. In opting for force sensor technology in its Adaptive Assembly Robotic Machine (AARM), Adaptive Intelligence Corp. has been able to target a wide variety of applications in the assembly of electronic, electromechanical, and other high-technology products.

SENSORS IN THE AARM

Strain gauges are built into the gripper of the AARM. These sensors make it possible to set three orthogonal (pinch, tip, and side) bidirectional programmable force thresholds, allowing for positional feedback to the robot controller. Through these strain gauges, the robot can determine a part's location and dimensional characteristics, which can then be compared to a part profile downloaded from a CAD parts inventory to determine whether the part is suitable for use. This positional feedback mechanism—integral to the AARM's IBM-PC-compatible controller—initiates exception-handling routines when a part is found that is out of tolerance.

The AARM also uses an optical sensor as an aid for positional feedback. The sensor's infrared light detects various assembly parts or elements between the gripper fingers. In typical applications, the optical sensor is positioned above a part to be picked up by the gripper. If the light beam remains uninterrupted, as when a part is missing, the AARM will implement an exception-handling routine. The scanner can also determine other variables with an assembly task. For instance, it can determine the size of various assembly elements by measuring the light beam. By moving from left to right, the scanner can determine the edges of various parts. By using this light-emitting diode in combination with a low-cost piece of tooling, the AARM is able to find the random location of screw holes, a job generally associated with machine vision.

USING FORCE SENSORS DURING ASSEMBLY

The three-dimensional information generated by the force sensors enables the AARM to be used in operations requiring a high degree of precision and repeatability. Through the strain gauges, the robot's controller collects information necessary for program origination, dynamic site location, and exception-handling routines.

At the start of each assembly operation, the AARM sets an origin for itself using a location post on the tooling plate, the Tooling Reference Post. By determining the post's exact location, the AARM identifies the positions of the other elements of the tooling plate, as well as the parts required for the assembly in relation to this origin. This ability to repeatedly set its origin allows maintenance to be performed and tooling plates to be easily changed without the need to reprogram all elements within the assembly environment.

Force sensing enables the AARM to determine dynamic site locations of elements within the workstation. For instance, the gripper is able to "feel" for a component or product entering the workstation from a conveyor belt even when the workpiece is not exactly where it should be. An additional command, GRASP, allows misoriented parts to be centered in the gripper during the part-pickup procedure.

Exception-handling routines are also initiated by the AARM's force sensors. The sensors in the gripper collect information on every part handled, enabling the controller to determine whether the part can

be used or must be rejected and replaced. Adverse conditions that occur during the assembly process can be monitored and corrected as required. The absence of a part can also be detected. Exception-handling routines include retrying the assembly task a predetermined number of times, selecting a substitute part, selecting an identical part from a different location, and—in extreme cases—suspending the assembly operation for manual interruption.

SENSORS AND THE PROGRAMMING LANGUAGE

A sensory-based programming language makes interaction between the sensors and the robot controller possible. Adaptive Intelligence has developed AAMPL (Adaptive Assembly Machine Programming Language), a high-level, user-oriented language for robotic control. AAMPL is extremely valuable for programming sensor-activated exception-handling routines, permitting constant comparisons between actual force values detected by the gripper during assembly operations with preprogrammed values. The controller is then equipped to respond to various assembly situations as they occur.

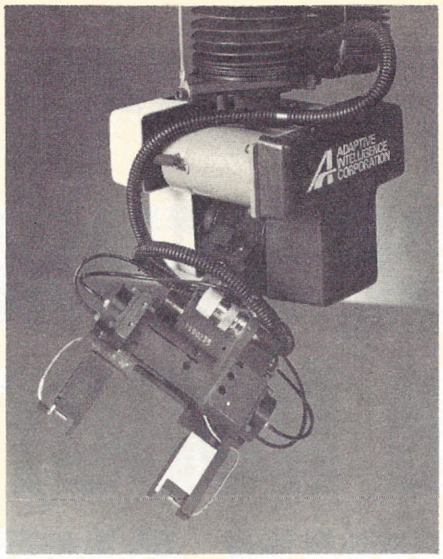

Photo 2. Strain gauges and an optical sensor are built into the gripper. Using these sensors, the AARM is able to perform such assembly tasks as "feeling" for a correct fit between parts and finding randomly located screw holes.

A brief example illustrates the use of sensors in programming with AAMPL. This program fragment commands the robot to pick up a special assembly tool, pick up a ring and place it on a post, then replace the tool.

```
 MOVE TO OVERTOOL
 MOVE TO TOUCHING, ACC=10, SPD=10
 MOVE TO LOCKON, ACC=5, SPD=5
 MOVE TO WITHDRAW, ACC=25, SPD=25
 MOVE TO OVERRING
GETRING:
 MOVE TO TOPRING
 MONITOR ENABLE, USING PINCH 0.5, GO TO HAVRING
 MOVE TO GRABRING, SPD=25
```

The program will branch at this point if the robot's gripping force is 0.5 pounds, signifying that the ring is present. If the ring is not at this location, the following exception-handling routine is activated.

```
 MOVE TO OVERRING
 DISPLAY WE HAVE GONE TO PICK UP THE RING BUT
   IT IS NOT THERE
 GO TO GETRING
```

After the ring is located and picked up, the gripper proceeds to place it on the post.

```
HAVRING:
 MONITOR DISABLE USING PINCH
 MOVE TO LIFTRING
 MOVE TO OVERPOST
 MOVE TO POSTBASE, SPD=15
 MOVE TO RELEASE
 MOVE TO OVERPOST
```

Once the ring is at the base of the post and the gripper is lifted, the tool is returned to its original location.

```
 MOVE TO WITHDRAW
 MOVE TO LOCKON, ACC=10, SPD=10
 MOVE TO TOUCHING, ACC=5, SPD=5
 MOVE TO OVERTOOL, ACC=25, SPD=25
```

FORCE SENSORS AND THE ELECTRONICS INDUSTRY

Force sensors can meet the present needs of electronics and high-technology manufacturing. The use of these sensors in robots with powerful controllers such as the AARM allows those robots to network within flexible manufacturing systems. Building on their present reliability and accuracy, force sensors will continue to pace the industry's needs in high-precision, high-speed robots.

Jim Breen is the Adaptive Intelligence Corporation's vice president for marketing and sales.

Reader Feedback

To rate this article, circle the appropriate number on the Reader Service card.

71	81	91
Excellent	Good	Fair

A MULTIELEMENT ULTRASONIC RANGING ARRAY

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One of the primary concerns in the development of a mobile robot design is providing the system with enough environmental awareness to make intelligent movement possible. A first step toward this end is to acquire appropriate information about ranges and bearings to nearby objects and to interpret that data.

Several ways to approach this problem have been proposed and investigated. They can be put into two categories: passive devices, such as stereoscopic vision and swept-focus ranging systems; and active devices, such as laser and ultrasonic range-finding systems. This article describes the most widely used ultrasonic ranging system employed today for this particular application (giving environmental awareness to a mobile robot), discusses some of the problems with this ranging system, and presents one means of overcoming these problems through the use of multiple transducers arranged in a sequentially fired array, with temperature compensation.

The ranging modules employed on ROBART II (see "A Second-Generation Autonomous Sentry Robot," *Robotics Age*, Apr. 1985) were made by Texas Instruments for use with the Polaroid electrostatic ultrasonic transducer and were selected for their low cost, high reliability, and ease of interface. An alternative system made by Massa Products Corp. (Model E-200) was evaluated but not selected because the unit price (over $160) made it impractical for a multielement array requiring several modules. By comparison, Polaroid offers both the transducer and ranging module circuit board for only $35 a set when purchased in quantities of ten. Texas Instruments has recently developed an improved version of the circuit board, the SN28827, which greatly reduces the parts count and power consumption, and simplifies computer interface requirements ("An Ultrasonic Ranging System," *Byte*, Oct. 1984).

Photo 1. Front view photo of prototype sentry robot ROBART II, showing location of sensors in 5-element sequential array. The single head-mounted sensor shown was later replaced by two sensors. The photo is courtesy of the Naval Surface Weapons Center.

The Polaroid ranging module is an active time-of-flight device developed for automatic camera focusing. It determines the range to target by measuring elapsed time between the transmission of a "chirp" of pulses and the detected echo. The one-millisecond chirp consists of four discrete frequencies transmitted back to back: 8 cycles at 60 KHz, 8 cycles at 56 KHz, 16 cycles at 52.5 KHz, and 24 cycles at 49.41 KHz. This technique is used to increase the probability of signal reflection from the target, since certain surface characteristics could in fact cancel a single-frequency waveform, preventing detection. It should be recognized, however, that the one-millisecond length of the chirp is a significant source of potential error, in that sound travels roughly 1100 feet per second at sea level, equivalent to about 13 in. per ms. The uncertainty and thus the error arises from the fact that it is not known which of the four frequencies making up the chirp actually returns to trigger the receiver. Even so, timing the echo always begins at the start of the chirp.

A second important characteristic of the Polaroid system is the use of a stepped gain control in the receiver section, where both the gain and the Q of the amplifier are increased as a function of time following chirp transmission. This ensures a high signal-to-noise ratio while matching the relative amplification level to the strength of the returned echo, which decays rapidly as a function of distance (and hence time). This becomes an important factor in the design of an array of sequential emitters, where residual or multiple echos could easily confuse the next element in the array. A faint residual echo generated by a previous chirp of another sensor probably would be too weak for detection by the now active range finder since its own gain had not yet been increased to the required level.

To understand the advantages of the sequential array, it is necessary to have a general understanding of the strengths and weaknesses of ultrasonic ranging, keeping in mind that the ultimate goal is to be able to repeatedly obtain accurate range information on objects surrounding a mobile platform. This dictates that power consumption be kept to a minimum and that the system be capable of operating in real time, which depends to some extent on how fast the robot travels. These two constraints make a mechanically positioned sensor less than desirable, because time and energy are wasted while the sensor is being repositioned to take ranges in a new direction.

The ideal solution would be to use a large number of prepositioned transducers that could be individually selected, enabling the robot to get range information in any given direction at any particular time. Since in reality each sensor is associated with some overhead in terms of physical space requirements, power consumption, interface circuitry, and acquisition cost, an array size of five transducers was chosen for ROBART II. On the robot's head two additional sensors were mounted that can be positioned up to 100 degrees either side of centerline. This configuration complements the fixed array for range finding outside its area of coverage.

For any ultrasonic ranging system, a multitude of error sources must be understood and taken into account. In the sidebar "Temperature Effects on Ultrasonic Ranging" it is shown that the speed of sound in air is proportional to the square root of temperature in degrees Rankine. For the temperature variations likely to be encountered in this application, this results in a significant effect, even considering the short ranges involved. Temperature variations over the span of 60 to 80° F can produce a range error as large as 7.8 in. at a distance of 35 ft.

Fortunately, this situation is easily remedied through the use of a correction factor based on the actual room temperature, available to ROBART II with an accuracy of 0.5° F from an external sensor mounted on the left access door. This sensor (Industrial Computer Designs, Remote Temperature Sensor RTS-1) produces an output voltage that varies from 0.80 to 4.80 V over the temperature range of 20 to 120° F and is interfaced to the system through one channel of an 8-bit multiplexed analog-to-digital converter.

The ranging units are calibrated at standard room temperature (70° F), and then the correction factor is applied to adjust for actual conditions.

The formula is simply: *actual range equals measured range times the correction factor, where the correction factor is the square root of the ratio of actual temperature to standard temperature, in degrees Rankine.*

Note that the range actually being measured does not always correspond to that associated with the beam centerline, as shown in Figure 1. The beam is reflected first from that portion of the target closest to the sensor. In fact, at a distance of 15 ft. from a flat target, with an angle of incidence of 70 degrees, the theoretical error could be as much as 10 in., since the actual line of measurement intersects the target surface at point B as opposed to point A. The problem is further complicated for surfaces of irregular shape.

The width of the beam introduces an uncertainty in the perceived distance between object and sensor but an even greater uncertainty in the angular resolution of the object's position. A very narrow

Temperature Effects On Ultrasonic Ranging

Speed of Sound $= c = \sqrt{g_c\, k\, R\, T}$

Where:

c	=	speed of sound (feet/second)
g_c	=	gravitational constant
k	=	ratio of specific heats (for air = 1.4)
R	=	gas constant for a specific gas
T	=	temperature (degrees Rankine)

Substituting in appropriate values for air yields:

$$c = \sqrt{(32.3)\,(1.4)\,(53.3)\,T} = 49.018\sqrt{T} \quad \text{ft/sec}$$

Which says the speed of sound in air is proportional to the square root of local temperature, in degrees Rankine (degrees Farenheit + 460 degrees).

At 70 degrees F: $c = 49.018\sqrt{460 + 70} = 1128$ ft/sec

At 30 degrees F: $c = 49.018\sqrt{460 + 30} = 1085$ ft/sec

Distance d traveled in feet over time t seconds is given by:

$d = ct$ which yields:

$d_A / c_A = t = d_S / c_S$ where subscripts S and A denote "standard" and "actual" conditions, respectively.

Thus the formula for the actual distance measured by an ultrasonic ranging unit calibrated at standard temperature T_S is:

$$d_A = (d_S)\,(c_A/c_S) = d_S\sqrt{T_A / T_S}$$

As an example, for a system calibrated at 80° F operating at an actual temperature of 60° F, a measured range of 35 feet corresponds to an actual range of

$$d_A = 35\sqrt{\frac{460 + 60}{460 + 80}} = 34.35 \text{ feet}$$

For an error of 7.8 inches

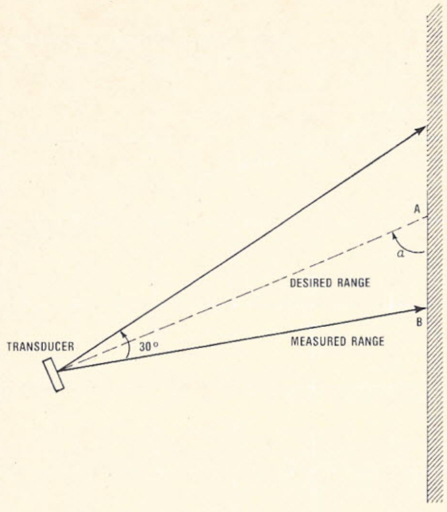


Figure 1. Due to beam divergence, ultrasonic ranging works best when the beam centerline is maintained normal to the target's surface. For off-normal conditions, the range measured does not always correspond to that associated with the beam centerline.

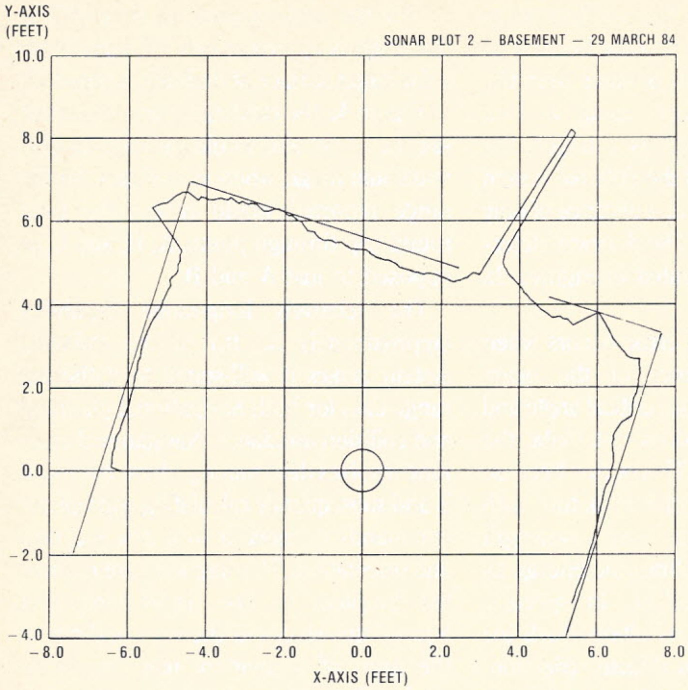
vertical target such as a long wooden dowel maintained perpendicular to the floor would have associated with it a relatively large region of floor space that would essentially appear to the sensor to be obstructed. Worse yet, an opening such as a doorway may not be discernible at all to the robot when only 6 ft. away, because at that distance the beam is wider than the door opening. In fact, using a 1-in. diameter vertical dowel as a target, the effective beam width of the Polaroid system was found to be 36 in. at a distance of only 6 ft. from the sensor. The doorway detection problem is illustrated in Figures 2a and 2b.

Another significant error occurs when the angle of incidence of the beam decreases below a certain critical angle and the reflected energy does not strike the transducer (Figure 3). This occurs because most targets are specular in nature with respect to the relatively long wavelength (roughly 0.25 in.) of ultrasonic energy, as opposed to being diffuse. In specular reflection, the angle of reflection equals the angle of incidence; in diffuse reflection, energy is scattered in various directions by surface irregularities equal to or larger than the wavelength of incident radiation. The critical angle is thus a function of the operating frequency chosen and the topographical characteristics of the target.

For the sensors used on ROBART II this angle is approximately 65 degrees for a flat target surface of unfinished plywood. In Figure 4a the ranging system would not see the target and would indicate instead maximum range, whereas in Figure 4b the range reported would reflect the total round trip through points A, B, and C as opposed to just A and B.

The relatively long-range capability (approximately 35 ft.) of the Polaroid system makes it well-suited to gathering range data for both navigational planning and collision avoidance. Navigational planning involves determining where the robot is and subsequently calculating appropriate commands to move it to a new location and orientation. The simplest case reduces the problem to two dimensions with a priori knowledge of the surroundings in the form of a memory map, or world model. The task becomes one of trying to correlate a real-world, sensor-generated image to the model and extracting position and orientation accordingly. Several factors complicate the problem.

For one, the real environment is three-



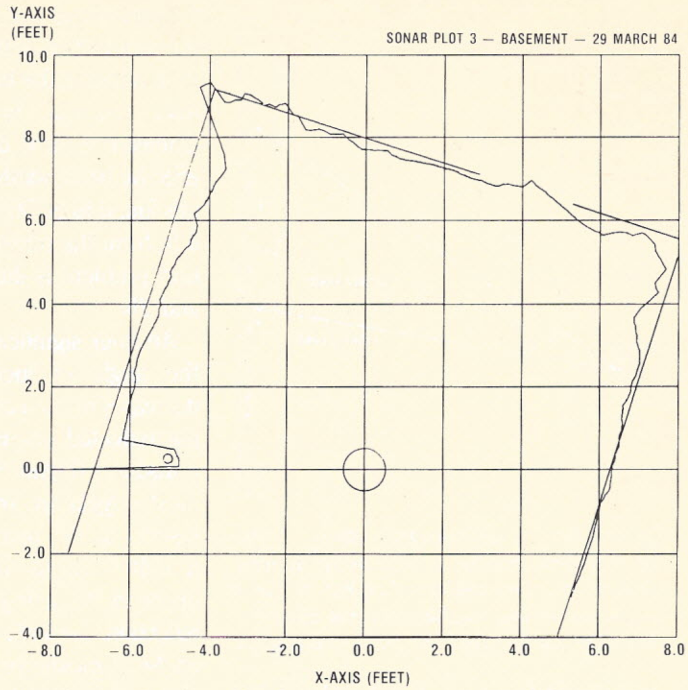


Figure 2a. Plot of 256 range readings taken by a single mechanically positioned sensor mounted on the head of ROBART II. An open doorway is detected in the wall approximately 5 ft. directly ahead of the robot. Note the excellent correlation with the actual wall location. The plot is courtesy of the Artificial Intelligence Laboratory, Massachusetts Institute of Technology.

Figure 2b. Plot of same room with the robot now 7 ft. from wall. Due to beam divergence the doorway is no longer detectable because at that distance the beam is wider than the door opening. The 256 range readings took approximately 7 sec. to collect. The plot is courtesy of the MIT AI Lab.

dimensional, and although the model represents each object as its projection on the X–Y plane, the sensor may see things differently, complicating the task of correlation. Second, large computational resources are required and the process is time consuming, requiring the robot to stop and think occasionally. Also, acquiring the data can take several seconds using ultrasonic ranging techniques, due to the relatively low velocity of sound waves in air. More important for the purposes of this discussion, however, are the effects of the various error sources previously described, which can act collectively to impede a solution.

Figure 2a depicts the results of 256 range values taken by a single sensor mounted on the head of ROBART II, with the robot approximately 5 ft. from the wall. The data took approximately 7 sec. to collect as the head was mechanically repositioned between rangings. The process could have been speeded up to some extent by reducing the number of range readings taken while the head was scanning. Note, however, that only two positions allowed the beam to pass through the doorway. Had the number of positions been reduced from 256 to 100, the doorway might have escaped detection altogether.

The exceptional quality of the plot is due primarily to the nature of the walls in a basement room with exposed studs that provided excellent beam return properties. The proper identification of the open doorway and the excellent correlation with the actual map would provide the robot with a highly accurate "fix." It should be noted that the room was fairly uncluttered, which is not always the case. In Figure 2b, the robot was repositioned 7 ft. from the wall and was unable to detect the opening. For such situations, the robot needs help from other types of sensors.

Collision avoidance is a little easier to address, in that accuracies are less important and the computational overhead nowhere near so great. The intent is simply to be aware of obstructions in time to alter course, assuming that the issue of updating the world model to reflect the presence of obstructions is deferred. For this application the sequential array can outperform a single sensor, in that the array permits range measurements to be made in many different directions very quickly and with minimal power consumption. Also, sequential arrays can use beam-splitting to improve the angular resolution, already shown to be extremely poor for a single transducer.

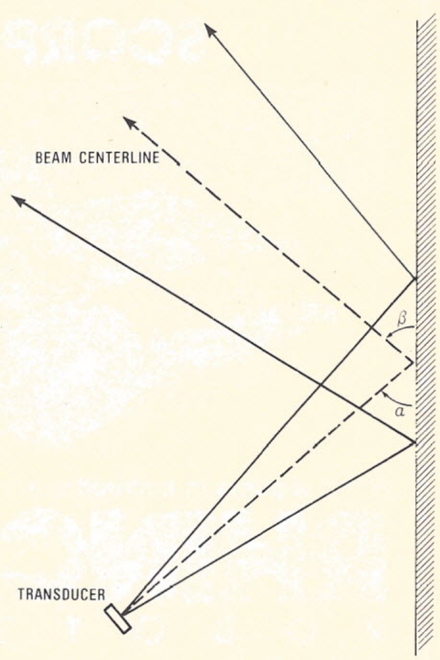


Figure 3. As the angle of incidence decreases below a certain critical angle, the reflected energy will not be detected by the transducer, resulting in erroneous range information. For specular reflection from smooth surfaces, the angle of reflection β is equal to the angle of incidence α.

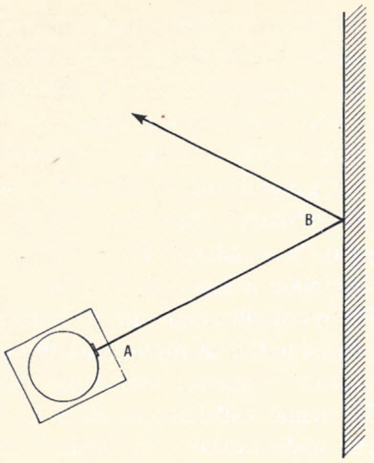


Figure 4a. For smooth surfaces, the ranging system will not see the wall ahead of the robot, and will erroneously indicate maximum range instead.

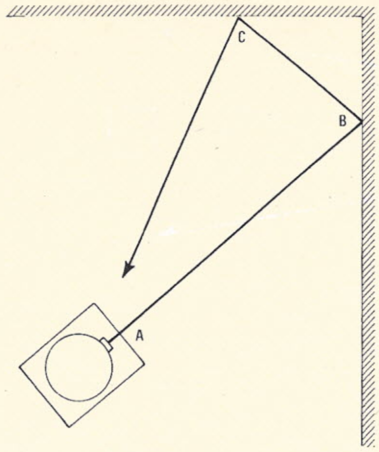


Figure 4b. The measured range will reflect the round trip distance through points A, B, and C as opposed to the actual distance from A to B.

Beam splitting involves the use of two or more rangefinders with partially overlapping beam patterns. Figure 5 shows how, for the simplest case of two transducers, twice the angular resolution can be obtained, along with a 50 percent increase in coverage area. The technique is simple: if the target is detected by both sensors A and B, then it (or at least a portion of it) must lie in the region of overlap shown by the shaded area. If detected by A but not B, the target lies in the region at the top of the figure, and so on. Increasing the number of sensors with overlapping beam patterns decreases the size of the respective regions and thus increases the angular resolution. The sensor pattern used on ROBART II allowed for an angular resolution of 2 degrees when locating a 1-in. vertical dowel 9 ft. from the robot, a significant improvement over the 30 degree resolution of a single transducer.

It should be noted, however, that this increase in resolution is limited to the case of a discrete target in relatively uncluttered surroundings, such as a metal pole supporting an overhead load or a box in the middle of the floor. No improvement is seen for the case of an opening smaller than an individual beam width, such as the doorway illustrated in Figure 2b. The entire beam from at least one sensor must pass through the opening without striking either side in order for the opening to be detected, and the only way to improve resolution for this case is to decrease the individual beam widths by changing transducers or through acoustical focusing, which sometimes is impractical.

The collision avoidance information gathered by the array can be used to approach or even follow an object. As ranges are repeatedly obtained along fixed bearings fanning out in the direction of travel, it is a fairly straightforward matter to track a specified target within the field of view even while both target and robot are in motion. ROBART II uses this technique when it is in the sentry mode to track an intruder detected by any of the system's many intrusion sensors. The robot's mean forward velocity is adjusted as a function of range to the target, and then a calculated differential in left and right drive motor speeds is introduced as a function of how far off centerline the target appears. This causes the robot to turn toward the target being followed in a controlled fashion, until it appears centered, all the while maintaining a specified interval.

The ultrasonic transducers on ROBART II are mounted from the inside of a 13-in. diameter section of plastic pipe that forms the upper body housing. To achieve the desired fanout angle of 9 degrees between beam centerlines for adjacent units, the mounting holes had to be staggered, essentially creating two rows, with three sensors on the bottom row and two on the top. To increase the vertical coverage, the top row

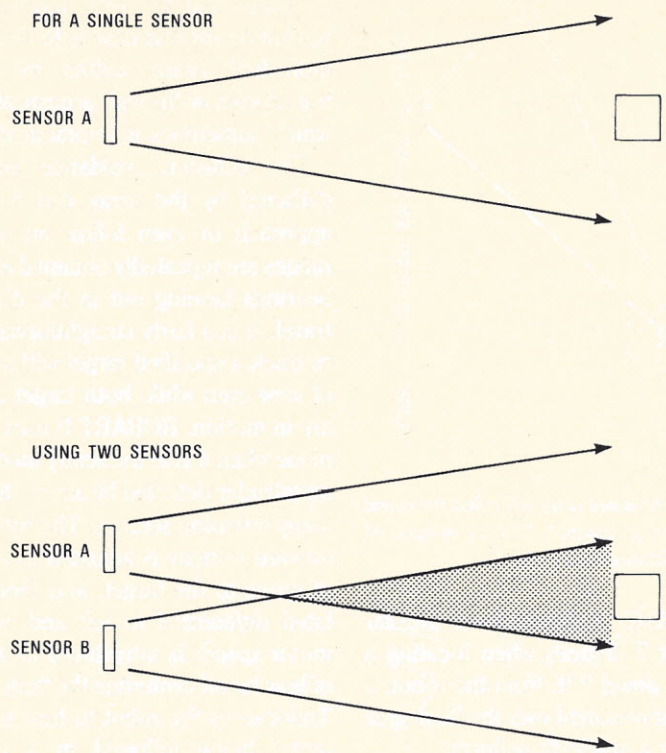


Figure 5. Beam-splitting techniques using two sensors can improve angular resolution by a factor of two while increasing the area of coverage by 50 percent. Further improvements can be gained by increasing the number of sensors with overlapping beam patterns.

was placed 11 in. above the bottom row, located 18 in. above the floor. Additional vertical coverage can be gained by placing one of the head-mounted sensors on centerline and operating it in conjunction with the array, thus providing maximum protection in the direction of travel for the full height of the robot.

To simplify the circuitry, all timing and time-to-distance conversions are done in software. Three control lines interface the Polaroid ultrasonic circuitboard to a microprocessor. The first of these, referred to as VSW (Figure 6), initiates operation when brought high to +5 V. A second line, XLOG, signals the start of pulse transmission, while the MFLOG line indicates detection of the first echo. The controlling microprocessor must therefore send VSW high, monitor the state of XLOG, commence timing when transmission begins (approximately 5 ms later), and then poll MFLOG until an echo is detected or sufficient time elapses to indicate the absence of an echo.

Since sound travels relatively slowly in air, a lot of CPU time will be wasted waiting for echoes, and fast range update rates will effectively tie up the microprocessor and interfere with other tasks. Fortunately, however, small dedicated controllers that can be slaved to the master microprocessor are readily available at low cost, and all-CMOS versions feature low power consumptions that make them attractive alternatives to specialized circuitry. ROBART II employs a 65SC02-based MMC-02 controller manufactured by R.J. Brachman Associates that is ideal for this task. Two 65SC22 Versatile Interface Adapters provide 32 general-purpose I/O lines as well as 8 handshake/control lines, with an 8-Kbyte on-board address space. Total power consumption is less than 35 mA.

The seven ultrasonic ranging units are interfaced to the microprocessor through a 3-circuit 8-channel multiplexer using 4051 analog switches operating in the digital mode, as shown in Figure 7. This way the microprocessor "sees" only one ranging unit at a time through the multiplexer, and the software merely executes in a loop, incrementing the Y register each time, which identifies the specific ranging unit to be enabled. Three I/O lines from the MMC-02 handle this enabling function, simultaneously activating the 4051 multiplexers for VSW, XLOG, and MFLOG. The binary number placed on these I/O lines by the microprocessor determines which channel is selected; all other channels assume a high impedance state. Three other I/O lines carry the logic inputs to the microprocessor from the multiplexer for VSW. To save battery power a final I/O line on the same port is used to power down the interface circuitry and the ranging units when not in use.

A second parallel port on the MMC-02 is used to receive commands from the Scheduler that tell the microprocessor to

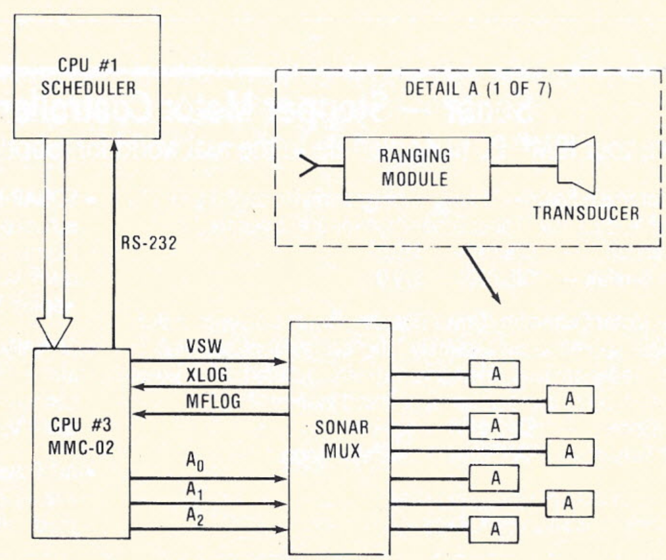


Figure 6. Block diagram of the multiplexed ultrasonic ranging system. CPU #3 "sees" only one ranging unit at a time, sequentially activating the modules upon command from the Scheduler. Stored ranges are transmitted up the hierarchy at the end of the sequence, which is then repeated.

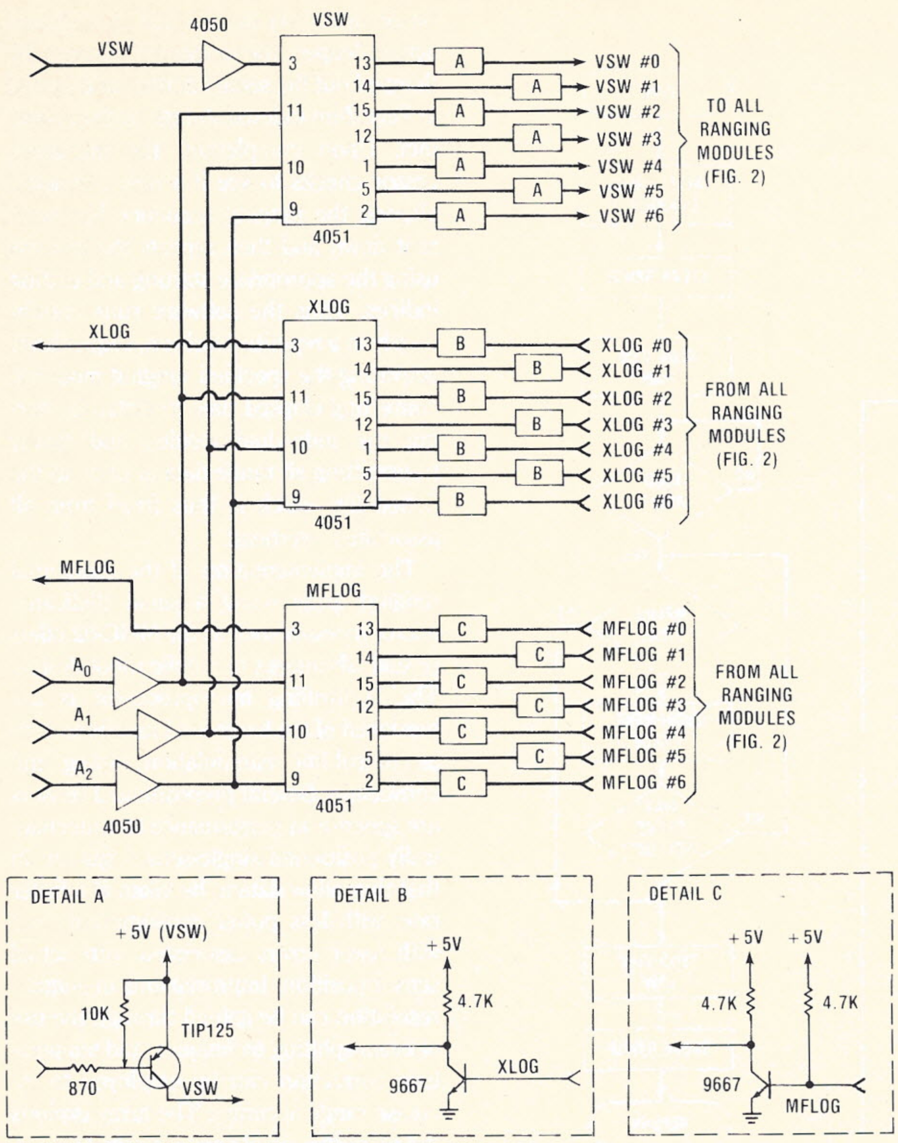


Figure 7. Schematic diagram for the multiplexer interface. The 4051 analog switches are operated in the digital mode with pins 6 and 7 grounded. Only one channel at a time is enabled, determined by the binary number on select lines A0, A1, and A2, set by the microprocessor.

power up the ranging units and specify which sensors to activate sequentially. Commands are in the form of an 8-bit binary number represented in hexadecimal format, where the upper nibble represents the starting ID and the lower nibble the ending ID for the sequence. For example, the command $16 would mean activate and take ranges using sensors #1 through #6 sequentially, whereas the command $44 would cause only sensor #4 in the array to be repeatedly activated. Each time through the loop upon completion of the sequence, the stored ranges are transmitted up the hierarchy to the Scheduler over an RS-232 serial link, with appropriate handshaking. The sequence is repeated in similar fashion until the Scheduler sends a new command down or advises the microprocessor to power down the ranging system with the special command $FF.

When energized by the Scheduler, the microprocessor does a power-on reset, initializes all ports and registers, and then waits for a command. When a command is latched into Port A of the 658C22, a flag is set automatically that alerts the microprocessor, which then reads the command and determines the starting and ending identities of the rangefinders to be sequentially activated. The interface circuitry and ranging units are then powered up, and the Y register is set to the value of the first transducer to be fired.

Subroutine PING is then called, which enables the particular channel of the multi-

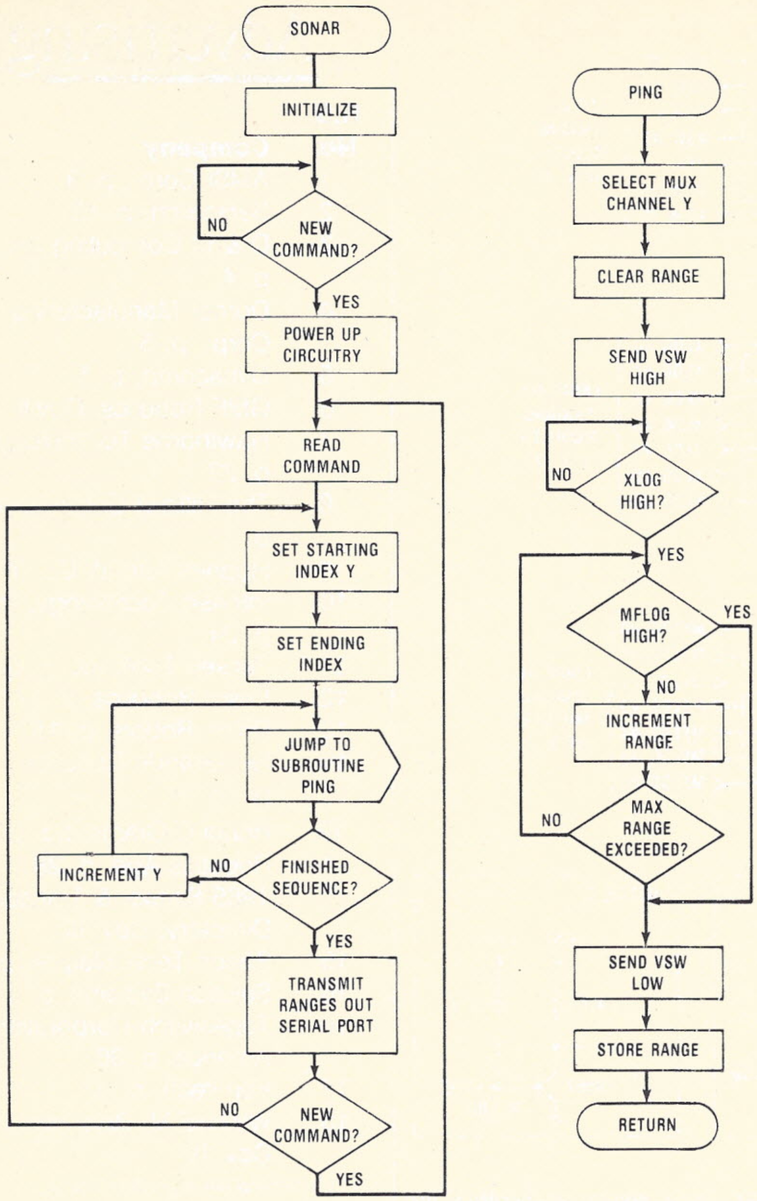


Figure 8. Flowchart for the system software which runs on the microprocessor. Subroutine PING activates and times individual ranging modules as dictated by the contents of the Y register. Commands are sent down by the Scheduler to specify the sequence of modules to be activated.

plexer interface dictated by the contents of the Y register. The VSW control line is sent high, which initiates operation of the selected ranging module. The software then watches the multiplexer output XLOG for indication of pulse transmission before entering the timing loop. Each pass through the timing loop corresponds to 0.10 in. in range measurement, since sound travels exactly 0.20 in. in the time required for loop execution at the system calibration temperature of 70° F. The contents of the loop counter register RANGE thus correspond to the number of tenths of inches to the target. If this value ever exceeds the maximum specified range of the system, the software will exit the loop, indicating no echo detection. Otherwise, upon exit from the timing loop, the range value for that particular ranging module is saved in indexed storage, and subroutine PING returns to the main program.

The Y register is then incremented to enable the next ranging module in the sequence, and subroutine PING is called again. This process is repeated until the Y register equals the value of the ending index, signifying that all modules in the sequence specified by the Scheduler have been activated individually. The microprocessor then requests permission from the Scheduler to transmit all the stored range values via the RS-232 port. When acknowledged, the ranges are sequentially dumped out the serial interface and placed in Page Zero indexed storage by the Scheduler. Upon completion, the microprocessor checks to see if a new command altering the ranging sequence has been sent down and then repeats the process using the appropriate starting and ending indices. Thus the software runs continuously in a repetitive fashion, sequentially activating the specified ranging modules, converting elapsed time to distance, storing the individual results, and finally transmitting all range data at once to the Scheduler, which is thus freed from all associated overhead.

The implementation of the sequential ranging array using a small dedicated microprocessor such as the MMC-02 offers several advantages to mobile robot design. The controlling microprocessor is unburdened of the lower-level functions such as control line manipulation, timing, and conversion. Several prepositioned sensors are superior in performance to a mechanically positioned single-sensor system, in that they allow data to be taken at a faster rate, with less power consumption, and with fewer errors associated with actual sensor position. Improvements in angular resolution can be gained through the use of beam-splitting techniques, and temperature correction can be employed to increase range accuracy. The array exploits the properties of ultrasonic ranging for collision avoidance or object tracking, where absolute accuracy is less important than relative information. For other applications in which precision *is* an important factor, such as navigation and map correlation in cluttered environments, complementary sensors with appropriate characteristics must be added. The relatively long wavelength, poor angular resolution, temperature dependence, and slow speed of sound in air become significant drawbacks, and near-infrared and laser-based rangefinders should be considered as alternative approaches.

Reader Feedback

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72	82	92
Excellent	Good	Fair

GOAL-SEEKING SENSOR

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New York Institute of Technology
Robotics Research Laboratory
Old Westbury, NY 11568
Source ID BCE252

Enabling a mobile robot to execute a task autonomously can be quite difficult, requiring high-speed processors with large amounts of memory, complex programs, and sophisticated sensors. The hardware for such a system is very expensive, and the software difficult to write. Autonomous robots usually rely on ultrasonic ranging systems, infrared room mapping, or path sensors to go about their work. Combining these methods can be costly in both hardware and software.

However, if the robot has one or more specific tasks, a goal-seeking mechanism can be implemented, making the hardware and the control software considerably less complex. Goal seeking can be defined as a system in which the autonomous or semiautonomous mobile robot has a predefined task to perform in a specific environment that is prepared with data-emitting devices the robot can sense. For example, an infrared emitter can be placed at the locations where a commercial mail delivering robot is to stop, or a speaker emitting a particular frequency can be placed at one end of a large factory floor, and another speaker emitting a different frequency at the other end. This arrangement would enable a robot with the proper sensors to transport materials from one side of the floor to the other.

Goal seeking, with obstacle avoidance routines, produces a robot that can maneuver itself through a complex environment toward a specified location. The resulting system is less complex and faster in operation, since it does not need to map its environment first and then make decisions based upon that map. Adding goal-seeking to path-sensing features increases the automatic guided vehicle robot's usefulness, enabling it to perform tasks when it reaches a designated location or locations, as in the case of the mail delivering robot.

One goal-seeking system can be constructed very easily: The data emitter can be in the form of a disk with several holes in it spinning in front of a standard light bulb. Figure 1 shows such a disk with 16 holes mounted on a phonograph motor which spins at 3600 rpm (60 revolutions per second). The disk produces a modulated light source of 960 Hz (16 holes × 60 revolutions per second). Figure 2 shows how this light can be detected using a phototransistor which feeds into an NE567 (PLL) which is configured as a tone decoder to sense the 960 Hz. A bandwidth of ±50 Hz has been incorporated to allow for power source variations and friction in the motor. Resistor R1 and capacitor C1 determine the frequency, and capacitor C3 determines the bandwidth. The output of the decoder at pin 8 oscillates when the detected frequency equals the reference frequency (960 Hz ±50 Hz). The pulsed output of the decoder is then latched by a 74LS123 which is configured as a retriggerable one-shot.

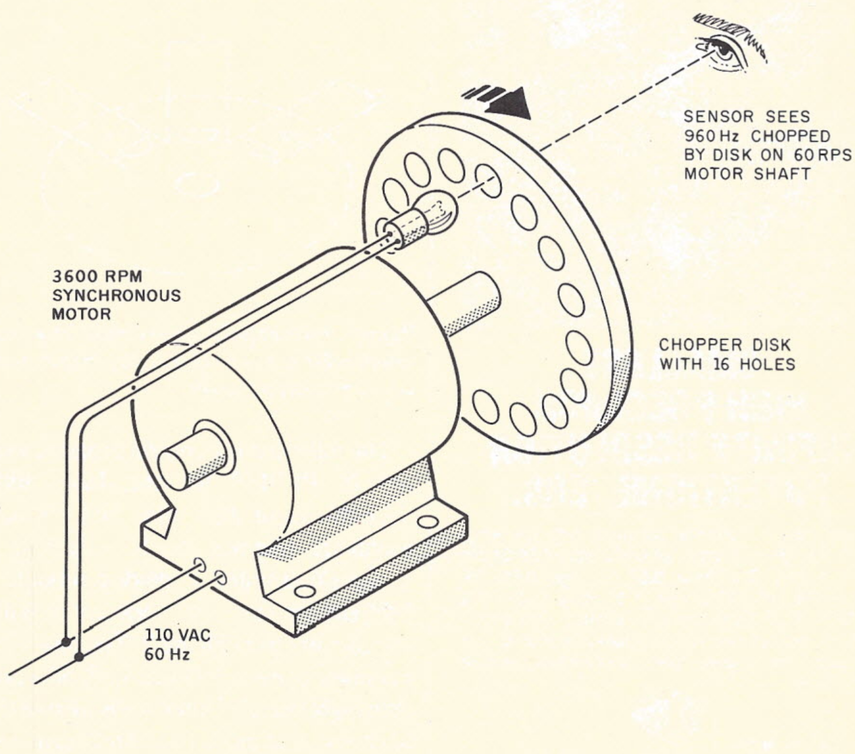

Figure 1. A brute force technique can be used to obtain an inexpensive source of light, modulated by a stable frequency. The 60 Hz frequency of the AC power mains sets the 3600 rpm rotation rate (60 rps) of the synchronous motor shaft. Sixteen holes in the chopper disk yield 960 pulses per second, rotating at 60 revolutions per second, i.e. 960 Hz.

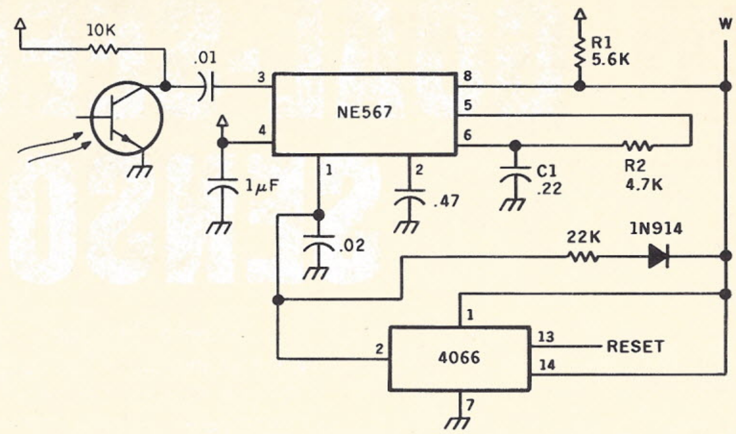

Figure 2. An NE567 phase lock loop circuit is used with a phototransistor to detect chopped light.

Three of these sensing circuits can be mounted on a disk with tubes placed around each phototransistor (Figure 3) which allows each transistor to receive the light in a directional fashion. If the disk is mounted on a stepper motor, it can be rotated until only the center phototransistor "locks" in on the signal, establishing the position of the light source. If two disks are mounted at a fixed distance from each other, triangulation can be used to even more accurately determine light source position, as well as its distance from the robot.

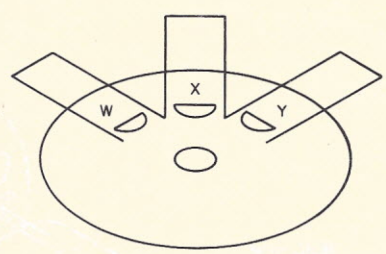

Figure 3. Three phase lock loop detector phototransistors, collimated by tubes on a scanning turret, are driven by a stepper motor.

The following is a control program written in PL/M86 for the Intel 8086 microprocessor illustrating how obstacle avoidance routines can be used with a goal-seeking system to guide a robot to a light emitter. Detection hardware includes the circuitry from Figure 2. The operating parameters are as follows: An 8255A programmable parallel interface is used in the latched output mode to control the motor. Stepper motor control requires a TTL direction bit. If this bit is high, then one rotation direction is used. If this bit is low, the motor steps in the opposite direction. A positive going edge transition moves the motor one step, which is an angle of 1 degree about its axis of rotation. An ultrasonic ranging control system generates an interrupt to the processor if a collision is imminent.

The code listed under SET$DISKL reads in the state of the six tone decoders. It then masks the data to check the left disk status. The tone decoder latches are cleared for updating. The first condition checked is to find out whether all three tone decoders are seeing the 960 Hz, a test conducted with the robot directly in front of the modulated light source. If the test is positive, an IN$FRONT$GOAL flag is set that can be passed to the NAVIGATION$ROUTINE algorithm. Program control is then passed to the CALCULATE$POSN section so the robot can calculate the position of the light source. The next test is to ascertain whether the W and X decoders are seeing the light. For this, the stepper motor is moved 1 degree to the left by jumping to L$SPIN$LEFT. This process will repeat until only the X decoder is locked onto the light source. Next, the Y and X decoders are tested in a similar fashion. If both are active, the motor is moved to the right until only the X decoder is locked onto the source. Finally, the X decoder is tested by itself. If the results are positive, the disk is assumed to be pointing directly at the light source. If all tests are negative, then a jump to LNOTIN$SIGHT rotates the disk to its left-most limit and begins searching for the light source. The SET$DISKR code repeats the same steps for the right disk.

Four routines are used to move the stepper motors. First a check is made to see

```
/*****************************************************************
* PL/M86 MODULE: GOAL$SEEKING                                    *
* MITCHELL S. ALEXANDER         NEW YORK INSTITUTE OF TECHNOLOGY *
*                                                                *
* FF00H,FF01H,FF02H ARE THE PORT LOCATIONS OF AN 8255A           *
* PARALLEL INTERFACE.                                            *
*                                                                *
* THE BIT ASSIGNMENT OF PORT FF01H IS AS FOLLOWS:                *
* LEFT DISK BIT 5=W, BIT 4=X, BIT 3=Y;                           *
* RIGHT DISK BIT 2=W, BIT 1=X, BIT 0=Y.                          *
*                                                                *
* THIS PROGRAM DEMONSTRATES HOW TWO PHOTOTRANSISTOR ARRAY        *
* (3 PER DISK) DISKS MOUNTED ON ONE DEGREE PER STEP, STEPPER     *
* MOTORS CAN BE USED TO GATHER DATA NECESSARY TO NAVIGATE        *
* TOWARDS A MODULATED LIGHT SOURCE OF 960 HZ.                    *
*****************************************************************


GOAL$SEEKER: DO;

             DECLARE

             MOTOR$CONTROL              LITERALLY      'OFF00H',
             DATA$IN                    LITERALLY      'OFF01H',
             RESET$PORT                 LITERALLY      'OFF02H',
             DISKL$LEFT$ON              LITERALLY      '1100B',
             DISKL$LEFT$OFF             LITERALLY      '1000B',
             DISKL$RIGHT$ON             LITERALLY      '0100B',
             DISKL$RIGHT$OFF            LITERALLY      '0000B',
             DISKR$LEFT$ON              LITERALLY      '0011B',
             DISKR$LEFT$OFF             LITERALLY      '0010B',
             DISKR$RIGHT$ON             LITERALLY      '0001B',
             DISKR$RIGHT$OFF            LITERALLY      '0000B',
             MASK$WL                    LITERALLY      '100000B',
             MASK$XL                    LITERALLY      '10000B',
             MASK$YL                    LITERALLY      '1000B',
             MASK$WR                    LITERALLY      '100B',
             MASK$XR                    LITERALLY      '10B',
             MASK$YR                    LITERALLY      '1B',
             RESET                      LITERALLY      '11111111B',
             LCOUNTER                   INTEGER,
             RCOUNTER                   INTEGER,
             IN$FRONT$GOAL              BYTE,
             DATA$IN                    BYTE,
             DATA                       BYTE,
             W                          BYTE,
             X                          BYTE,
             Y                          BYTE;

SET$DISKL:   DATA = INPUT(DATA$IN);
             W = DATA AND MASK$WL;
             X = DATA AND MASK$XL;
             Y = DATA AND MASK$YL;
             OUTPUT(RESET$PORT) = RESET;
             IF W= MASK$WL AND X= MASK$XL AND Y= MASK$YL THEN DO;
                    IN$FRONT$GOAL=1;
                    GOTO CALCULATE$POSN;
                    END; /*IF THEN AND DO*/
             IF W = MASK$WL AND X= MASK$XL THEN GOTO L$SPIN$LEFT;
             IF Y =MASK$YL AND X= MASK$XL THEN GOTO L$SPIN$RIGHT;
             IF X =MASK$XL THEN GOTO SET$DISKR;
             GOTO L$NOT$IN$SIGHT;

SET$DISKR:   DATA = INPUT(DATA$IN);
             W = DATA AND MASK$WR;
             X = DATA AND MASK$XR;
             Y = DATA AND MASK$YR;
             OUPUT(RESET$PORT) = RESET;
             IF W= MASK$WR AND X= MASK$XR AND Y= MASK$YR THEN DO;
                    IN$FRONT$GOAL=1;
                    GOTO CALCULATE$POSN;
                    END; /*IF THEN AND DO*/
             IF W =MASK$WR AND X= MASK$XR THEN GOTO R$SPIN$LEFT;
             IF Y =MASK$YR AND X= MASK$XR THEN GOTO R$SPIN$RIGHT;
             IF X = MASK$XR THEN GOTO CALCULATE$POSN;
             GOTO R$NOT$IN$SIGHT;

L$SPIN$LEFT: IF LCOUNTER>0 THEN DO;
             OUTPUT(MOTOR$CONTROL) = DISKL$LEFT$ON;
             OUTPUT(MOTOR$CONTROL) = DISKL$LEFT$OFF;
             GOTO SET$DISKL;
             END; /*IF THEN DO*/
             ELSE GOTO L$NOT$IN$SIGHT;

L$SPIN$RIGHT:IF LCOUNTER <360D THEN DO;
             OUTPUT(MOTOR$CONTROL) = DISKL$RIGHT$ON;
             OUTPUT(MOTOR$CONTROL) = DISKL$RIGHT$OFF;
```

Continued on page 24

Continued from page 23

```
                        GOTO SET$DISKL;
                        END; /*IF THEN DO*/
                        ELSE GOTO L$NOT$IN$SIGHT;

R$SPIN$LEFT:  IF RCOUNTER>0 THEN DO;
                        OUTPUT(MOTOR$CONTROL) = DISKR$LEFT$ON;
                        OUTPUT(MOTOR$CONTROL) = DISKR$LEFT$OFF;
                        GOTO SET$DISKR;
                        END; /*IF THEN DO*/
                        ELSE GOTO R$NOT$IN$SIGHT;

R$SPIN$RIGHT: IF RCOUNTER<360D THEN DO;
                        OUTPUT(MOTOR$CONTROL) = DISKR$RIGHT$ON;
                        OUTPUT(MOTOR$CONTROL) = DISKR$RIGHT$OFF;
                        GOTO SET$DISKR;
                        END; /*IF THEN DO*/
                        ELSE GOTO R$NOT$IN$SIGHT;

L$NOT$IN$SIGHT:
                        DO WHILE LCOUNTER>0 OR (INPUT(DATA$IN) AND MASK$XL =
                           MASK$XL);
                                OUTPUT(MOTOR$CONTROL) = DISKL$LEFT$ON;
                                OUTPUT(MOTOR$CONTORL) = DISKL$LEFT$OFF;
                        END; /*DO WHILE OR*/

                        DO WHILE LCOUNTER <360 OR (INPUT(DATA$IN) AND
                           MASK$XL = MASK$XL);
                                OUTPUT(MOTOR$CONTROL) = DISKL$RIGHT$ON;
                                OUTPUT(MOTOR$CONTROL) = DISKL$RIGHT$OFF;
                        END; /*DO WHILE OR*/

                        GOTO SET$DISKL;

R$NOT$IN$SIGHT:
                        DO WHILE RCOUNTER>0 OR (INPUT(DATA$IN) AND MASK$XR =
                           MASK$XR);
                                OUTPUT(MOTOR$CONTROL) = DISKR$LEFT$ON;
                                OUTPUT(MOTOR$CONTROL) = DISKR$LEFT$OFF;
                        END; /*DO WHILE OR*/

                        DO WHILE RCOUNTER<360 OR (INPUT(DATA$IN) AND
                           MASK$XR = MASK$XR);
                                OUTPUT(MOTOR$CONTROL) = DISKR$RIGHT$ON;
                                OUTPUT(MOTOR$CONTROL) = DISKR$RIGHT$OFF;
                        END; /*DO WHILE OR*/

                        GOTO SET$DISKR;

CALCULATE$POSN:
                                        .
                                        .
                                        .
                        CALL NAVIGATION$ROUTINE;
                        GOTO START;

END GOAL$SEEKER;
```

that they are not moving past their preset limit of 360 degrees. Each motor is pulsed high and low, moving it one step. Program control is then passed back to the SET$DISK routines. If a motor is at one of its limits, the proper NOTINSIGHT routine is used to locate the light source.

The CALCULATE$POSN routine can be written in various ways, depending upon how much memory is available and whether a math coprocessor such as the 8087 is used. One method uses the Law of Sines to solve the sides of the oblique triangle formed by the two disks and the light source. A sine lookup table can be placed in memory to help speed up calculations. Once the position is known, program control can be passed to a navigation control routine. After the course is computed and execution begins, the entire process is repeated.

The goal-seeking system is an inexpensive, comparably easy way of enabling a mobile robot to accomplish one or several tasks. Although ultrasonic ranging systems are useful in a goal-seeking system, they are not necessary. If they are used, a single transducer can do the job. The goal-seeking method serves to simplify and to reduce the costs of a mobile robot.

Reader Feedback

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73	83	93
Excellent	Good	Fair

THE ACCUKNIFE™

When Davidson Rubber Company, Inc. decided to streamline its foam rubber cutting process, it went robotic. The 122-year-old Farmington, New Hampshire firm, a division of Ex-Cell-O Corp., makes instrument panels for automobiles, an operation that entails excising a number of variously shaped blocks from a large rectangle of foam rubber. Under the old system, the blocks were cut out with hot knife dies mounted on presses, but the cuts tended to be only 70 percent complete and a secondary hand trim was necessary.

Accuratio Systems, Inc. (ASI) of Clawson, Michigan supplied Davidson with five water jet cutting gantry-style machines called Accuknives, built at the company's Jefferson, Indiana plant. Equipped with five-axis capability, the robots carry on their wrists slender nozzles through which coherent streams of water travel at 3000 feet per second under a pressure of 55,000 pounds per square inch. The jets slice along at 2400 inches per minute. According to a Davidson spokesman, the hot knife dies could trim out more parts per hour, but the jets' 100 percent initial cut has proved an acceptable tradeoff.

Tool rotation can be up to 580 degrees on the A (fourth) axis and 360 degrees on the B (fifth) axis. Both axes maintain the same dispense point regardless of their positions, a feature ASI describes as unique and which it terms "constant focus." The cutting heads, moved by servomotors and ball screws, normally have tolerances in the 0.010 range but can be tightened up to ± 0.001 inch for high-precision applications.

In addition to making a complete cut on the first pass, the water jets offer other advantages over hot knife dies. Because they exert only 10 pounds of pressure, the jets do not crush the foam. Further, the kerf, or groove, they leave is very small since the cutting force is confined to the size of the jet itself, about 0.000008 square inches. The cutting force is dynamically applied and does not disturb material adjacent to the kerf. The edges are always a square 90 degrees, ASI says.

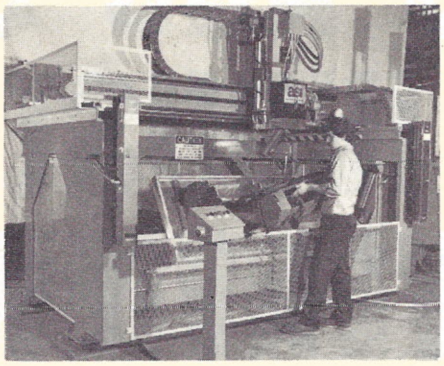

Photo 1. The positioning fixture tilts forward when the cutting cycle is complete, presenting the instrument panel for a worker to remove. The steel mesh guard keeps operating personnel at a safe distance, and scanner panels on the left and right of the gantry frame provide a light curtain that automatically shuts off the machine when the curtain is penetrated.

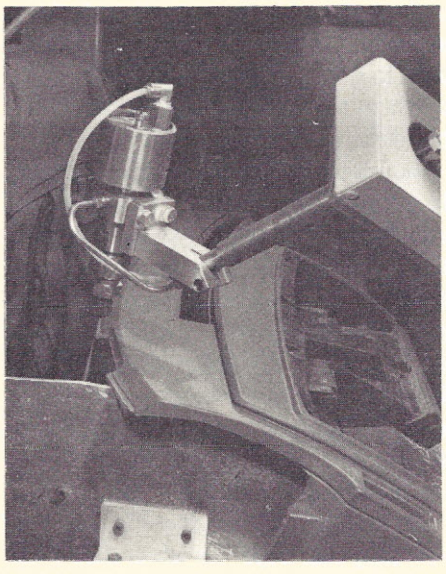

Photo 2. A close-up of the cutting head shows the jet stream at work trimming a panel edge. All cutting action takes place within approximately 1 1/2 inch from the nozzle outlet.

Water jets were chosen over laser cutters for several reasons, according to Davidson. The ASI system was less expensive and more ready-to-go. Also, lasers would have produced both char and toxic fumes.

The robots take their orders from Allen-Bradley Series 8400 computerized numerical controllers built into the workcells. The CNC can operate from RAM, ROM, magnetic tape, or paper tape. Multiple programs can be stored, and when a mix of parts is coming down the line, the appropriate guidance program for any given part can be selected manually or by sensing units on the cell. Davidson's machines are dedicated in that they have to date been used only for cutting instrument panels. However, they have proved easy to convert from the pattern configuration of one sort of panel to that of another, Davidson says.

Several safety devices come built into the ASI robots, and others were added by Davidson. The CNC provides each axis with soft limits that prevent movement beyond the machine's operating range. Each machine has limit switches and cams that disconnect the power to the drive motors should any axis travel beyond its soft limit. Whenever power and air are shut off, a spring-loaded brake is released to hold the robot's Z (vertical) axis in position. At the Davidson plant, humans and robots are kept safe from each other by a light curtain, steel mesh fencing around the machinery, and automatic dump valves. There is also a warning sign on the robot: "CAUTION This machine is automatically controlled and may start at any time. Always open circuit breaker before working on equipment."

The ASI water jet robots are also used to cut corrugated boxboard, particle board, graphite, ceramics, printed circuit boards, and even thick slabs of granite and stainless steel. For some materials, a long-chain polymer is added to the water stream to improve jet coherence. An abrasive can also be introduced into the stream when steel or another very hard or dense material is to be cut. The system's high energies cause each particle to work hard, and the cut edges have a polished appearance.

ROBOTS AND SAFETY: AN INDUSTRY OVERVIEW

Stephanie vL Henkel

The idea of robot workers has been a familiar theme since the 1930s. No one who grew up reading science fiction ever doubted that robotic automation was just around the corner, but no book could have completely prepared today's factory worker for the form robots have taken. For the predictions were of robotic factories humming along totally on their own, or "manned" by robotic creatures built in human form. Humans would either be out on the golf course while their work was being done for them, or enjoying a coffee break with their steel friends.

As the science has turned out, today's robots (except for the novelty varieties) don't resemble humans in the least, and they still require some human attention. The question that must be addressed is how to make the working relationship between humans and robots a safe one. Should humans be kept away from robots, or robots from humans? Or is a close human-robot connection possible?

No to the latter, says Dr. Warren P. Seering, associate professor of mechanical engineering at the Massachusetts Institute of Technology. Robots are machines, should be built in the form of machines, and treated like machines. "The concept of robots as mechanical humans has prompted engineers to attempt to design robots to recognize when a person enters their workspace, and to react accordingly. The implication has been that humans and robots are coworkers . . . After all, few people perceive an arbor press or a packaging machine as a coworker. And no one would expect a computer-controlled lathe to stop cutting just because someone touched the spindle. People have no business touching the spindle."

Industrial safety engineers have generally taken a different tack, raising three aspects of robot safety again and again: training or retraining all personnel who will be sharing a factory floor with a robotic machine, designing the robot's workspace with an eye to the safety of the humans with authority to enter it, and erecting barriers to keep out the unauthorized and sensors to shut the robots down in case an intruder still manages to get in.

Turret lathes are machines and so are robotic arms. Both can do certain jobs more quickly and with greater precision than can humans. But there the significant similarities end. Robots can move in unexpected paths and at varying speeds. They can change direction without warning when the programming calls for a change. When the power goes off in the plant, not all robotic movement necessarily stops—loads being carried can crash to the floor or become projectiles, or the entire arm can swiftly fall onto whatever or whoever is underneath. Workers must be taught that because a robot is at rest it will not necessarily remain motionless, or because it has been repeating a particular pattern it will continue to do so.

To date, only three robot-related fatalities have been reported, two in Japan and one in the United States. The figure is probably correct, but as automation becomes more widespread, the number of industrial accidents—and deaths—could increase exponentially.

Two sources of danger, according to Lloyd R. Carrico of INFAC, are the human characteristics of curiosity and complacency. When a robot is first brought into a manufacturing plant, everyone wants to get a close look. Just as some foolhardy visitor to a zoo tries to pat a bear, a worker decides to try to outwit or dodge a robotic arm. Once the robot has become a familiar sight, complacency sets in. A worker headed for the cafeteria takes his old route and walks right through the robot's workspace. Carrico says that not only an initial education about industrial robots is necessary but that frequent updates must be given so the machinery, in effect, stays new and a bit foreign to plant employees.

Most robot-related mishaps have occurred while a robot was being trained or serviced. Both activities require that someone enter the robot's work envelope, which is an extremely hazardous place to be unless the power is completely shut off and all robotic motion has ceased. But

teaching a robot must be carried out under power, as must certain maintenance operations.

A number of safety features can be engineered into the robotic system. Others must be devised at the place of installation.

When a trainer goes into the robot's work envelope to teach it a job the robot should be under the control of only the teacher. Except for an emergency stop button on the master controller, which should be located outside the robot's reach, there should be no way another person can give a command to the robot. During the training session the robot should be made to move in slow motion; one suggested pace is 250 millimeters per second, or about one-third normal operating speed.

Safety features can be built into the teach pendant. Carey Moore, safety supervisor of Oldsmobile, recommends two: an emergency stop button on the pendant or a deadman switch arrangement, in which a pistol grip must be squeezed at all times to activate the robot. Both, Moore says, should be hard wired into the stop circuit and not connected through a computer interface.

An electrical interlock should be installed so no two robots that are side by side can be in the teach mode at the same time, and a red strobe light should be activated to indicate which robot is being taught.

Moore recommends also that each robot have two disconnects, one for the drive and the other for the encoder. That way, when the power is off and the robot moved manually the computer will know precisely where the robot is when power is restored. Backup battery units built into the processor are a good idea too so RAM memory is not lost during a power glitch.

Hardware stops and brakes should be strong enough to stop a robot in a runaway condition at maximum speed with maximum load and with the load at a position to cause the highest operating forces, says Forrest Leipold, contract administration manager of Prab Robots, Inc. Posts or stanchions should not be used to halt a runaway because they could form pinch points, areas in which the teacher or maintenance worker could be trapped and crushed.

Leipold suggests as well that robots with electronic controllers should be protected from electromagnetic and radio frequency interference that could affect the controller and cause the robot to move erratically. Noting that power surges of 1000 to 2000 volts over reference value of 460 volts have occurred, as well as time drifts of ± 50 to 75 volts over 5 to 10 cycles, Leipold says a reliable earth ground is essential.

When a teacher or maintenance person enters a robot's work envelope, a hold or interrupt switch stops all programmed motion but leaves the power on. This switch is usually placed on a gate in the protective fencing around the envelope. Carrico proposes that a second switch be installed outside the fence, one that must be turned on in order to reactivate the robot. Such an arrangement would require the person to leave the envelope, close the gate, and then hit the outer switch before the robot could resume its run mode.

The National Bureau of Standards is working on yet another approach to robot safety. The Watchdog Safety Computer (WDSC) has been devised to detect operations that are outside the range of normal conditions with the purpose of preventing the robot from damaging itself or any of the equipment or sensors on or around it in the event of a hardware malfunction, software bug, or operator error.

The WDSC prototype, hooked up to a Cincinnati Milacron T3 robot, is mounted in its own chassis and has sole control of the system bus. It monitors the robot's individual joint and tool point motions along with other status signals from the hydraulic pump unit and the controller. It also keeps track of the robot's six joints, measuring every 50 milliseconds the amount of rotation from a known home position, rotational velocity, and rotational acceleration. If an unacceptable deviation from the standard is detected, the WDSC stops the robot and alerts the operator.

Robot system engineering is geared toward protecting those who have business within the work envelope but it is up to plant safety personnel to protect those who do not. Ideally, an education and awareness program would discourage the reckless and keep the absent-minded on their toes. Such is not the case in reality, though, so a combination of reminders and physical barriers is in order.

The most basic reminders are lines, usually yellow ones, painted at the periphery of the danger areas. Warning signs should be posted, and robots under drive power should wear amber lights to advise caution. Other passive safety measures include wire mesh fencing, chains, and guardrails. The fencing should be eight feet high and heavy enough to require the use of tools to cut through it. (In the amount of time a really determined intruder would need to get to the robot, other plant personnel would presumably see what was happening and put a stop to it.)

There are also active safety measures that, when tripped, shut down robotic operation. Pressure-sensitive floor mats are in particularly wide use. Relatively inexpensive and simple to install, the mats respond to a pressure of 30 pounds. Their unobtrusiveness, however, produces one drawback—plant employees must take care not to set an object on a switch mat or accidental downtime will result. Light curtains are popular too even though they cost more. They work best in a relatively clean environment where particulate matter will not break the curtain and put the robot on hold.

Other safety systems under development use ultrasonics, microwave, infrared, and capacitance devices controlled through software that can detect the presence of humans. General Motors is working on a magnetic field detector that would equip robots with antennas that put out a magnetic field. The robot learns the normal path and what the magnetic field should be in that path. When the field is interrupted the robot shuts down.

The National Bureau of Standards is developing a very sophisticated system that would recognize three levels of penetration into the robot's work area and make a response appropriate to the situation, eg., treating an object left in the work envelope differently from a teacher in the same area. The responses would include a complete shutdown, a slowdown, and activation of alarms, sending the robot to work in another zone until the intruder has left, and obstacle avoidance.

The NBS system prototype combines pressure-sensitive mats with ultrasonic echo-ranging sensors, consisting of five electrostatic transducers mounted on a Stanford Arm robot. Signals indicating an approaching intruder are ignored until the intruder reaches a minimum distance, set at one foot from the robot. At that point the robot stops and stays on halt until the

intruder leaves. It then resumes operation from the position it was in when stopped.

Even the most imaginative futurist of as recent a decade as the 1960s would not have recognized today's robots as robots. Very few even faintly resemble humans, and their microprocessor-based intelligence would be incomprehensible to anyone trying to make it in one leap from vacuum tubes—or even transistors—to silicon chips. The unexpected direction of robotic evolution has produced unanticipated hazards to challenge the ingenuity of design safety engineers. After the engineers have done their work, it is up to the rest of us to treat robots as what, after all, they are: intelligent machines.

> The robots created by Isaac Asimov in his 1939 novel, *I, Robot,* were endowed with a form of intelligence that 46 years later remains several robotic generations in the future. Asimov gave his creations three laws: 1. A robot may not injure a human being, or, through inaction, allow a human being to come to harm. 2. A robot must obey the orders given to it by human beings except where such orders would conflict with the First Law. 3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

For Further Reading

Carrico, Lloyd R. "A Comprehensive Approach to a Safe Implementation of Industrial Robots." Paper presented at the Robotics Safety Conference, Oakland Univ., Rochester, MI (June 1983).

Kilmer, Roger D. "Safety Sensor Systems for Industrial Robots." Paper presented at the Robots 6 Conference, Detroit, MI (March 1982).

Kilmer, Roger D., Harry G. McCain, Maris Juberts, and Steven A. Legowik. "Watchdog Safety Computer Design and Implementation." Paper presented at the Robots 8 Conference and Exposition, Detroit, MI (June 1984).

Leipold, Forrest. "Robot Construction (Safety Considerations)." In *RIA Robot Safety Seminar Proceedings.* Dearborn, MI: Robotic Industries Association. 1985.

Moore, Carey. "Robot Safety Training for Oldsmobile Employees." In *RIA Robot Safety Seminar Proceedings.* Dearborn, MI: Robotic Industries Association, 1985.

Seering, Warren P. "Building Robots in the Image of Machines." *Technology Review.* Cambridge: MIT Press (April 1985).

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74	84	94
Excellent	Good	Fair

Edited by Stephanie vL Henkel

AN INTERVIEW WITH PHILIPPE VILLERS

Artificial vision is now and will continue to be "king" of machine sensing systems, according to Philippe Villers, "just as in the natural world the eyeball is the king in man and beast. Artificial vision has the maximum flexibility, it is the least specialized, and it has the greatest applicability."

Villers, the founder and chairman of the board of Automatix, Inc., is more recently the founder and president of Cognition Inc., based in Burlington, Massachusetts. Automatix is among the leading developers and suppliers of machine vision systems for robotics applications including welding, assembly, and inspection. The new company is developing mechanical and electrical second-generation computer-aided engineering systems.

Villers prefers the term "artificial vision" to the more traditional "machine vision." The reason, he explained, is a semantic one: "Artificial vision carries a connotation of artificial intelligence, to which it is more allied. Machine vision, to me, has a more inflexible connotation, as in machine tools or machines in general." Artificial vision, he pointed out, offers a good linguistic contrast with "natural vision."

Villers became interested in artificial vision early on. In the late 1970s, when he was senior vice president of Computervision Corp., he proposed that the company diversify into robotics because of "the great promise" offered by what were at that time only theoretical approaches to machine vision. Since then, he has seen three major advances in the field: moving from binary to gray scale vision, the "enormous" lowering of costs, and the close integration of vision systems with robots. The next major hurdle, he said, is "to proliferate vision systems. What is now proved needs to become commonplace." As for his own personal interest in new developments, Villers said he was "looking forward to the power of the latest VLSI semiconductor technology's being used to drastically reduce the cost of vision capability."

The semiconductor industry's current woes are only part of a regular cycle, Villers said, but he added that the U.S. "must once again be pioneers in new areas." One of the reasons it has become difficult for this country to keep up with foreign competitors is that "the other major countries have done a much better job in putting together government, education, and industry. In Japan, government and education are partners of industry," Villers said. "In the United States they are barely on speaking terms." Villers suggests that "unless we act to correct these problems, we can't compete with countries that already offer lifelong education programs." Reflecting on the difference in direction between Japanese and American engineering, Villers said, "Japan wants to excel in consumer and industrial goods. In the United States we try to excel in missiles. Maybe we'll both get our wish."

If you keep robots and humans apart, you solve most of the safety problems.

Asked about artificial vision as it applies to robotic safety, Villers said, "If you keep robots and humans apart, you solve most of the safety problems." He does not advance vision as appropriate in safety applications because it is "costly and it is not obvious that it is fail-safe." Multiple cameras as safety devices around a robot workstation, he said, are not in the near-term future. At Automatix, safety concerns were present from the beginning, Villers said. Chain fences, pressure-sensitive mats, and light fences were installed first and prominent power-on lights were added to the robots. The machines also have fail-safe circuits, dependable for electric robots which are the only sort Automatix uses.

"Switch mats as a safety approach make a great deal of sense," Villers said. "Unless someone's trying to play Tarzan, it's difficult to get from here to there without using the floor." He favors the mats for their "unobtrusiveness, ruggedness, simplicity, and generally very affordable cost." Light curtains are a "reasonable alternative," he said, but cost more. (A voice

recognition systems developer approached Villers some time back to ask his opinion as to the effectiveness of such a system as a robotic teaching input device. The inquirer wanted to know the vocabulary range Villers thought would be sufficient, and Villers said: "One word: 'Stop.' ")

As robots stream into the workforce they are presumably becoming more familiar sights and their potential danger better known. The question has been raised as to where safety responsibilities should rest, upon the robots' manufacturers or on the people who work in automated plants. Villers made an analogy between robots and automobiles: "People see a car and know what it is," he said, "but they still step out in front of it." Robotic manufacturers should be required to build safeguards into their machines. "How long would it have taken market demand to have caused the seatbelt to become universal? There is a proper role for regulation; it can be overdone, but that doesn't mean there is not a legitimate role in issues of safety."

The future of robotics, Villers said, will bring less in the way of physical changes in the machines than it will in the software. The degree of a robot's intelligence will distinguish one machine from another. "Which is more important these days," he said, "brawn or brains?"

Agreeing with several recent studies on the subject, Villers anticipates a "significant" shakeout in the artificial vision industry, now estimated to be growing at about 100 percent a year, and predicted that Automatix will be among the survivors and in fact, a leader. Other approaches to machine sensing will continue to have a sound position in robotics, in particular ultrasonic, touch, and proximity sensors. But, as Villers put it, "artificial vision is the most powerful, versatile sensing device. I think that's a fair summary."

MARKET RESEARCH

The concept of developing a manufacturing automation protocol (MAP) has been overshadowing the "real issues," according to a study conducted by **Cadlinc, Inc.** The program, begun by General Motors to standardize the ways computers, programmable controllers, and robots talk with one another on the factory floor, addresses only the physical aspects of integration, says Cadlinc Production Manager John Mahr. Issues needing more attention than they have been receiving include: • What unique features of the U.S. manufacturing environment need to be addressed? • What needs to be done to implement effective automation and computer integrated manufacturing (CIM)? • What is the role of MAP in the broad implementation of CIM? Achieving true integration and effective automation in the factory will require more than physical links among devices. Changes will be necessary in corporate cultures and approaches to business, Mahr said.

CORPORATE NEWS

► **GMF Robotics** will supply over 200 painting robots to **General Motors Truck and Bus Division** and **GM's Buick Motor Division.** The contract, estimated at more than $80 million, is described by a GMF spokesman as the largest in the robotics industry.

► **General Electric** has signed a memorandum of understanding with **Shanghai Machine Tool Corp.** and **Shanghai Machine Tool Research Institute**, both in the People's Republic of China, to begin marketing computerized numerical control in that country. The terms of the agreement call for the Mark Century® One and the AC200 servodrive to be distributed and serviced. Later, both product lines will be manufactured in the PRC.

► **Automation Intelligence, Inc.** has signed an OEM agreement with **Graftek** to market AI's generalized postprocessor. Graftek will be selling the product as a part of its numerical control software package to provide the interface for CAD/CAM systems and NC machine tools.

► **Mobot Corp.** has announced an agreement to merge with **Advanced Manufacturing Systems, Inc.** Lawrence Kamm, Mobot's former president, will remain with the company only as a shareholder.

► **BankAmerica Corp.** has announced the sale of **Decimus Corp.** to **General Electric Credit Corp.** Decimus, which finances high-tech equipment to corporations, has been controlled by BankAmerica since 1969.

► **Litton** has received a $4 million FMS contract from "a major auto manufacturer" to automatically control the production of cam grinders at one of the auto company's V-8 engine facilities.

► **American Robot Corp.** has signed an agreement with **Fairey Automation Ltd.** for exclusive OEM marketing rights to the British firm's MetaTorch, a vision guidance system for arc-welding robots. American Robot plans to integrate its Merlin robot system and controller with the MetaTorch and market the packaged product in the U.S. as the Merlin Visiontracker.

► **Industrial Networking, Inc.** has been selected by four companies as the supplier of manufacturing automation protocol-based local area network components and systems. The companies are **Intel Corp.**, **Motorola Corp.**, **GMF Robotics**, and **Electronic Data Systems.**

► **Western Technologies Automation, Inc.** has been awarded a contract from **Solitron Devices, Inc.** for an automatic semiconductor die sorting system. The system permits inkless testing and sorting of a die into multiple output grades.

► **Cincinnati Milacron** has formed a Laser Systems Division. Headed by Barr Klaus, the new division will be responsible for integrating industrial lasers with the company's other products including machine tools, industrial robots, and electronic controls.

PEOPLE

► **Marc W. Carlson** has been named sales manager of North American Automotive Components for **GMF Robotics.** His prior experience was with GM and TRW.

► **James R. Swartz** has been elected chairman of the board of directors of **Perceptron.** Swartz has been a member of the firm's board since its founding in 1981. He is managing partner of Accel Partners and director of several publicly traded companies as well as a number of private high-technology ventures. **James K. West**, Perceptron's vice president of product development, has been appointed to a one-year term as the first president of the Machine Vision Association of the Society of Manufacturing Engineers. He was also named to a two-year term on the association's board of directors.

► **Samuel J. Harris** has joined **Odetics, Inc.** as program development manager for aerospace systems after a 27-year career with McDonnell Douglas Corp. Harris's new appointment was described by Odetics as "coinciding with the release of a NASA technical report on automation and robotics for a manned space station."

► **Mortimer J. Sullivan** has joined **American Technologies, Inc.** as director of marketing and sales for the firm's Automated Factory Systems Division. Sullivan's previous experience was with ASEA, Unimation, and AMF.

► **Jack Worthen** has been appointed product marketing manager for **Data Translation**'s module and personal computer analog I/O product lines. He was previously with Hybrid Systems Co.

► **James Van Osdol** has been named to the board of directors of **Cybot, Inc.** He is general manager of the Illuminated Displays Division of Bell Industries and will advise Cybot on engineering, planning, and general management issues.

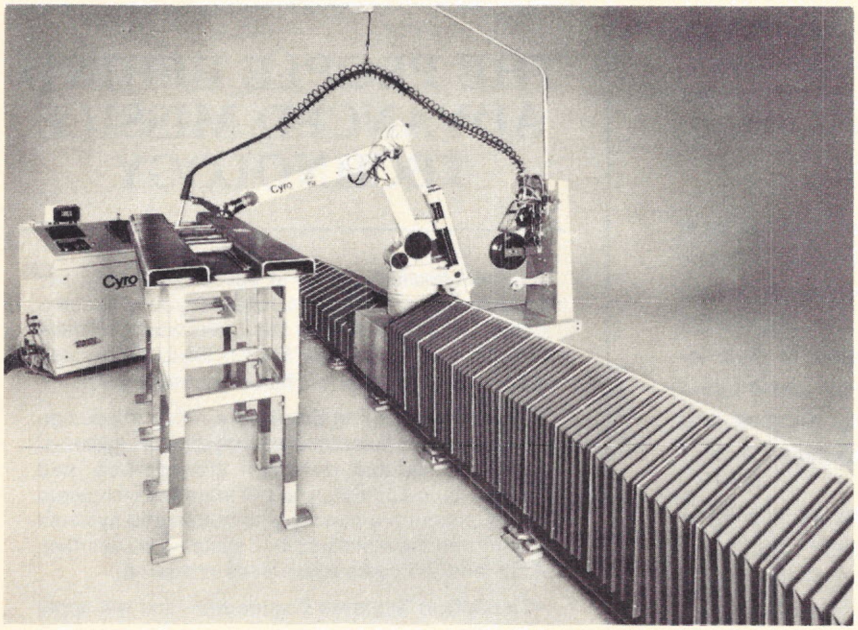
► **Faraj Mahdavi** has been named president and chief operating officer of **Key Image Systems, Inc.** He will replace Fery Aalam, who will become chairman of the board and CEO. Mahdavi, who founded Gulf Data, Inc., will continue as president and CEO of that company, which is now a wholly-owned subsidiary of Key Image.

► **Dr. David P. Gutman** has been named vice president of marketing of **GCA/Industrial Systems Group.** Gutman holds three degrees in mechanical engineering. He was formerly with Scott Paper Co.

► **Donald F. McCook** has been named by **Gould, Inc.** as president and general manager of the Design and Test Systems Division. His previous experience was at Vicom Systems, Inc., Amtel Systems Corp., Pacific Northwest Electronics, and John Fluke Manufacturing Co., Inc.

► **Edward L. Fournier, Jr.** has been appointed national sales manager of **CNC** (Computer Numerical Control Corp.) He has formerly been employed by Megatest, Accutest, and Adar Asso.

New Products



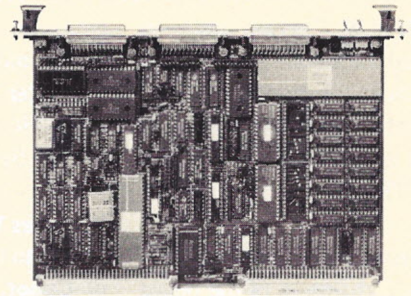
Traverse Axis for Arc Welding Robots

Advanced Robotics Corporation now offers an optional traverse axis for its Cyro 1000 robotic arc-welding work cell. This new feature increases the robot's work envelope by allowing the robot to weld parts on both sides of the axis. A Cyro 1000 mounted on a 23.0 foot X-axis extension has a work envelope of nearly one million cubic inches.

The X-axis extension permits welding of longer, larger parts and allows a single robot to service multiple work stations. To accommodate loading or unloading of very large parts, the robot can be moved to the opposite end of the extension, out of the way of any overhead interferences. This extension gives users the option of having the robot travel to the workpiece rather than bringing the workpiece to the robot. It is available in lengths of 8.2, 16.4, and 23.0 ft. with speeds of up to 20 in. per second.

For more information, contact: Advanced Robotics Corporation, 777 Manor Park Dr., Columbus, OH 43228, telephone (614) 870-7778.

Circle 30



VMEbus Single-Board Computer

The PME 68-1B, an expandable 16-bit VMEbus singleboard computer, takes advantage of the high-speed capability of the MC68000 microprocessor. Furnished as a double Eurocard, it can provide 24 address lines, 16 data lines, priority bus arbitration, interrupt control, system clock generation, and special control lines for data handling.

The PME 68-1B can function as the sole bus master or in a multiple processor environment. In addition, the board supplies the address modifier lines necessary to determine whether short, standard, or extended addressing is being used. The board comes with a 16 Kbyte system monitor that contains terminal control of the debug, up- and downloading, and memory modify instruction. It also provides one-line assembly/disassembly and full access to 16 Mbytes of memory space.

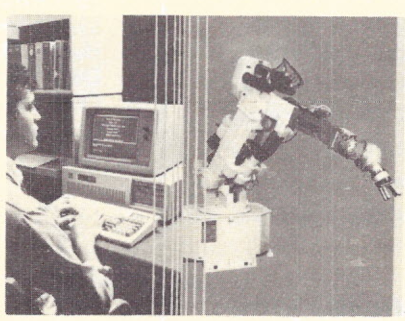
For more information, contact: Plessey Microsystems, One Blue Hill Plaza, Pearl River, NY 10965, telephone (914) 735-4661.

Circle 31

Robot Off-Line Programming System

Cincinnati Milacron's new Robot Off-Line Programming System (ROPS) is a coordinated package of software modules developed for use with the company's T³ 700 and T³ 800 series robots and its Version 4 robot control. ROPS enables the user to create new robot programs and edit existing ones at the keyboard of a host computer while the robot continues production on the shop floor.

ROPS is a modular, file-based system that can be custom-tailored to any application. The basic system consists of a programming module that processes data from a wide range of sources to create the robot program, a translator module that transforms existing programs for off-line editing by the programming module, and an STR-Link Data Cartridge Reader Module that interfaces ROPS with the robot control. Optional modules include CAD/CAM interfaces, a communications module for program storage and editing, and a front end for data entry.

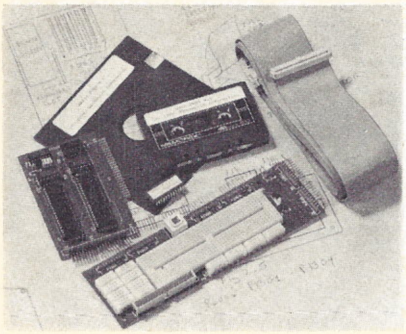


ROPS is capable of alignment, for positioning and programming of symmetric parts; path generation for both straight and circular paths; and calibration, for improved robot accuracy based on real-world data.

For more information, contact: Tom Thomas, ROPS Product Manager, Cincinnati Milacron, Industrial Robot Division, 215 S. West St., Lebanon, OH 45036, telephone (513) 932-4400.

Circle 32

New Products



Robi 4.0: Apple-Hero Interface

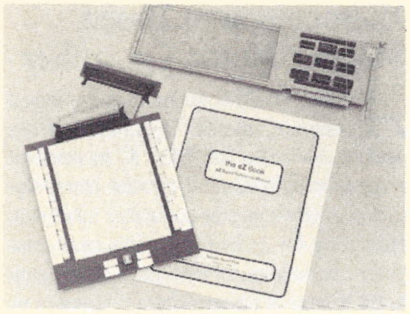
Bersearch Information Services is offering a kit designed to make your Apple shake hands with your Hero I. The package includes a 5¼ in. floppy disk with software for the Apple, a data cassette with software for the Hero, a replacement Experimental Robot Board, an Apple board, a 6-ft. cable, a 2716 EPROM with alternate software for the Hero, and a highly detailed instruction manual addressed to both the beginner and the advanced user.

The Hero software receives files from or sends them to the Apple; its 177 bytes require only 4.6 percent of user memory. Robi's Apple board plugs into slots 1–7 of an Apple II. Its four ports are implemented on the Apple with two Motorola 6821 peripheral interface adapter chips.

This interface makes it possible to develop and store programs on the Apple's disk drives and then download them into the Hero's computer.

For more information, contact: Tom Bernard, Bersearch Information Services, 26160 Edelweiss Circle, Evergreen, CO 80439, telephone (303) 674-8875.

Circle 33



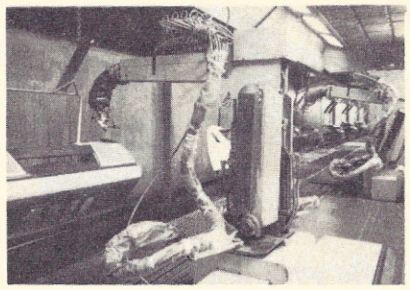
Prototype Development Board for PCs

The eZ-SYSTEM from Sabadia Export Corp. is described as a complete hardware development system that provides direct I/O capability for the most popular personal computers. It consists of the eZ-BOARD, a solderless breadboard that provides direct access to bus, power, and control signals; and the eZ-CARD, a prototyping board that fits inside the system being interfaced. The card allows up to 60 16-pin dip sockets for wire-wrapping custom logic configurations and serves as the intermediate buffered interface between the PC and the eZ-BOARD.

The card also offers switch-selectable address decoding, allowing up to eight eZ-SYSTEMs to interface to a single IBM PC. A technical guide is part of the package.

For more information, contact: Rafe Husain, Vice President, Sales, Sabadia Export Corp., PO Box 1132, Yorba Linda, CA 92686, telephone (714) 630-9335.

Circle 34



Lightweight Automatic Color Changer

Tokico America has developed a lightweight automatic color changer designed to be mounted directly on the articulated arm of an ARMSTAR spray painting robot. Since color change valves are located close to the spray gun, the color change sequence quickly cleans the short paint hose and gun between colors, making it ideal for high-speed random part painting. Up to 27 colors can be handled by one changer.

Until now, according to the company, arm mounting of color changers has been largely unsuccessful in the U.S. due to heavy, unwieldy color change mechanisms mounted on "flimsy" robot arms that have caused the computerized finishing programs to malfunction. Tokico claims to have solved this problem by coupling its precision lightweight color change mechanism with a more powerful robot arm and point-to-point programming mode.

For more information, contact: Tokico America, Inc., Robotics Division, 15001 Commerce Dr. North, Dearborn, MI 48120, telephone (313) 548-1480. Circle 35

Expert System Development Tool

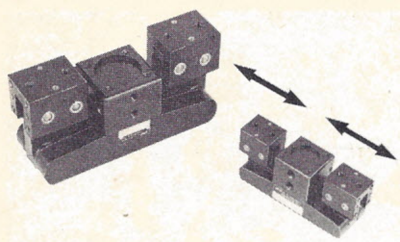
Expert-Ease, described as the only expert system development tool designed for nonprogrammers with no knowledge engineering background, is being offered by Jeffrey Perrone & Associates. The function of Expert-Ease is to turn a microcomputer into an "apprentice" by providing an easy-to-use spreadsheetlike format on which the user, or "craftsman," can provide teaching examples. The information is presented in terms of questions and answers that lead to a conclusion. Examples are provided of the decisions the user might make under a variety of circumstances, and the system automatically determines the underlying decision-making process this information represents.

The examples are presented to Expert-Ease as a list of answers to questions considered by the expert to be relevant to the problem area. The final entry for each example is the decision (or result) for the example. From these examples, Expert-Ease derives a classification in the form of a decision tree. If a new example is found that refutes the current rule, the system can be commanded to restructure the rule so it can accommodate the new case. Unnecessary complexities and inconsistencies in decision making can be quickly identified and resolved, the company says.

For more information, contact: Jeffrey Perrone, President, Jeffrey Perrone & Associates., Inc., 3685 17th St., San Francisco, CA 94114, telephone (415) 431-9562.

Circle 36

New Products



Lightweight Parallel Gripper

A new lightweight, compact parallel motion gripper is now available from PHD, Inc. The company describes the parallel jaw motion as an ideal end effector when weight and size are critical because the jaws can maintain a consistant gripping area and force throughout their travel.

The pneumatically operated gripper offers gripping forces to 360 lbs. The jaws are low profile with drilled and tapped holes for easy mounting of tooling for either internal or external gripping. The gripper is available in four sizes, each with an optional Hall effect sensor/transducer that provides four or more adjustable position outputs for use as jaw position feedback.

For more information, contact: PHD, Inc., PO Box 9070, Fort Wayne, IN 46899, telephone (219) 747-6151. Circle 37

Laser System for Marking Circumference of Cylindrical Parts

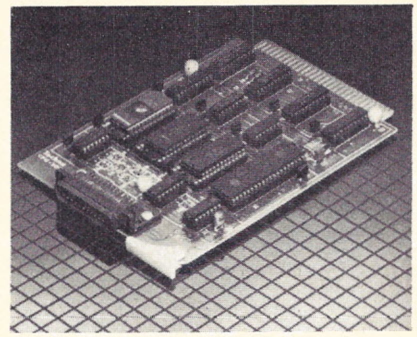
Quantrad has announced a new laser marking system said to be uniquely engineered to mark completely around the circumference of cylindrical parts. The Cylindrical Parts Marker (CPM) combines the company's Blazer™ 2000 computer-controlled YAG laser with a parts delivery and positioning system. The positioner is a rotationally synchronized robotic arm that allows a part to be precisely rotated to match the laser's scanning speed. The CPM system can mark bar code, alphanumerics, or both, 360 degrees around a part. No other laser marker in current production can do this, the company says.

For more information, contact: Quantrad Sales Group, 19900 S. Normandie, Torrance, CA 90502, telephone (213) 538-9800. Circle 39

Microcomputer-Based Stepper Motor Controller

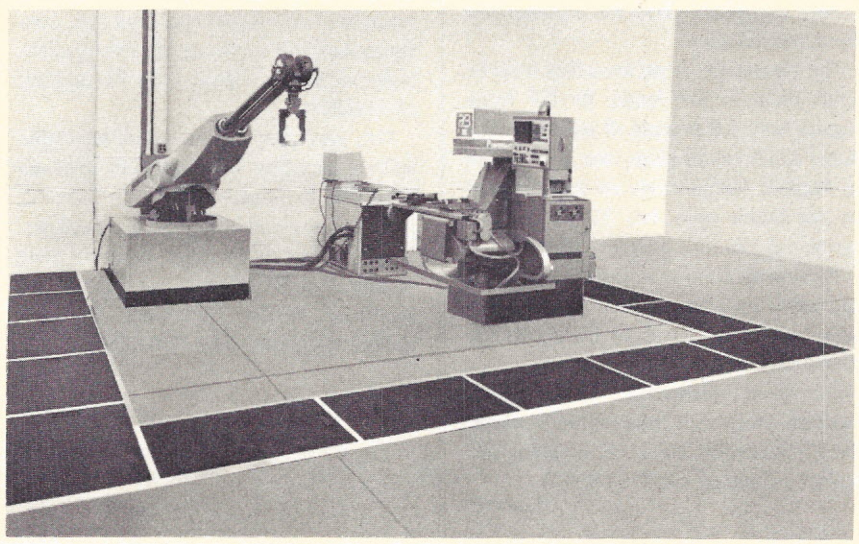
A new STD-BUS microcomputer-based stepper motor controller from Techno, Inc. uses the 8031 IC to perform programmed linear and circular interpolation plus other master controller functions. Measuring 4½ in. by 6½ in., this microcomputer card is ideal for processes needing up to 64 Kbytes of either program memory or data storage, the company says, and was designed to work with many standard I/O boards and ½ amp driver cards.

As a microstep controller, the card can independently command up to four motors in linear motion or two motors in circular motion. In the microstep mode, up to 12,800 steps per revolution are currently possible. In full- or half-step modes, the controller can independently command up to



eight stepper motors. The card is capable of carrying out two independent sequences simultaneously. Applications include industrial process controls, factory automation, robotics, and general instrumentation areas.

For more information, contact: Herb Arum, Techno, Inc., 2101 Jericho Turnpike, New Hyde Park, NY 11040, telephone (516) 328-3300. Circle 38



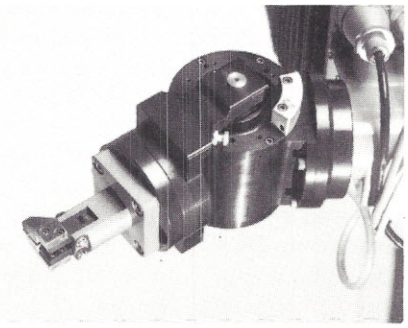
Pressure-Sensitive Safety Mats

Switchmats, available from the Recora Co., are designed to shut down robotic operation when a worker accidentally enters the robot's workspace. The entire surface of the mats is sensitive to foot pressure, the company says, yet it can withstand forklift truck traffic. Installations can be custom-tailored to fit areas of any shape or size.

The mats can also be wired so that the operator must step on a mat to activate machinery, doors, or other equipment. Specially engineered fail-safe control units connected to 110 V, 60 cycle, AC outlets are available as options to monitor and provide recommended low-voltage power (8 amps) for Switchmat operation. The circuitry warns of short circuits and power failure.

For more information, contact: Hal Goetsch, Recora Co., Powis Rd., PO Box 1220, St. Charles, IL 60174, telephone (312) 584-3000. Circle 40

New Products



Fifth-Axis Robot Wrist

Developed to fit the Seiko D-TRAN RT series and the TT 3000 robots, the Chad fifth-axis wrist expands the robot's standard four axes. The wrist is mounted to the A-axis of the robot's arm for movement close to the work surface. The dual-action pneumatic-driven wrist can be set at any two stops up to 190 degrees apart. Solid-state limit sensing feedback is optionally available.

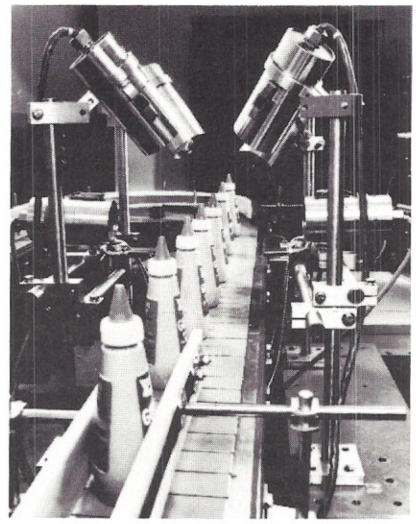
For more information, contact: Dean Williams, Vice President, Marketing, Chad Industries, 1060-K N. Batavia St., Orange, CA 94567, telephone (714) 997-4350.

Circle 41

Machine Vision at Production-Line Speeds

Eaton Corporation's QR4000 is a new automated vision system that provides presence/absence, registration, orientation, dimension, and full-view quality inspection at production-line speeds of up to 100 objects per minute.

The system consists of multiple 16-bit microprocessors, up to four cameras with strobe lights and mounting hardware, a portable programmer with either keyboard or CRT/light pen data entry and set-up provisions, a video monitor, power supplies, and cables. During operation, the cameras, strobes, and object-sensing markers are located at the points of inspection. Each image is digitized by the processor for comparison to a reference image stored in memory. System accuracy and resolution are governed by each camera's pixel array of 320 by 240 elements that provide up to 76,000 bits of data. Each pixel is sensed on a 64-shades-of-gray scale. The manufacturer offers a full turnkey package for both new and retrofit installations.



For more information, contact: Mr. E. Sabinash, Eaton Corporation, 4201 N. 27th St., Milwaukee, WI 53216, telephone (414) 449-6000.

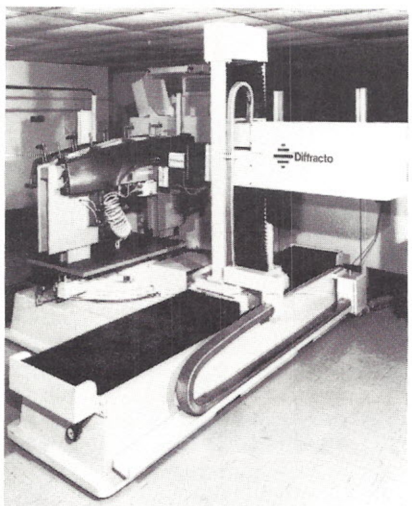
Circle 42

Noncontact Vision Sensor Measuring Robot

The RoboGage™ 642 system, a four- to six-axis measuring robot with noncontact vision sensors that gauge sheet metal panels, has been introduced by Diffracto, Ltd.

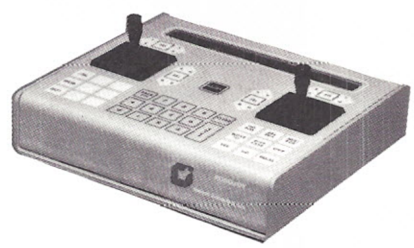
After a metal panel is clamped into a fixture similar to a traditional ring gauge, the RoboGage arm manipulates a dual Laser-Probe noncontact sensor around the perimeter of the panel. Fit (gap and flushness) is measured by optical triangulation, and surface features such as hole size and position are defined by the imaging portion of the same sensor. As the arm steps around the outer edge of the panel, the sensor measurements are compared to the CAD database of the part. A graphics CRT displays the gauge points and deviation as well as the value of each consecutive measurement.

According to the company, the system's advantages include faster measurement than that of traditional ring gauges, the ability to measure fit and surface features, programming flexibility for different parts, ruggedness for use right on the plant floor, and totally direct computer control.



For more information, contact: Victor J. Wolanski, Marketing Manager, Diffracto, Ltd., 6360 Hawthorne Dr., Windsor, Ontario, Canada N8T 1J9, telephone (519) 945-6373.

Circle 43



Dual Joystick Teach Pendant

ROBOJOY, from Robotic Computers, Inc., is an intelligent teach pendant for use with all robot controllers that have an RS-232 port. The pendant's dual joysticks, English language keys, and 80-character LCD were designed to permit rapid programming by nontechnical personnel.

ROBOJOY also features 38 different host commands to configure it for compatability with the user's controller and an internal beeper for signaling errors and user prompts.

For more information, contact: Mark Joseph, Robotic Computers, Inc., 602 Park Point Dr., Golden, CO 80401, telephone (303) 526-0100.

Circle 44

Small Parts Conveyor System

A versatile system for moving small parts has been developed by Gulf+ Western's Advanced Development and Engineering Center. The U-TRAN is modular in design and differs from conventional conveyors in its extruded U-shaped base in which the belt assumes the same U form, never allowing the parts being carried to touch the conveyor's sides. The arrangement also maintains orientation of the parts.

The conveyors can be provided with fixed or variable-speed drives in widths of 2, 4, and 6 inches. Available in floor-mounted, ceiling-hung, or inclined configurations, the conveyors are offered in standard 10 ft. lengths or as custom-engineered systems with thousands of feet of interconnected/multi-track components. Applications include the conveyance of fasteners, electronic components, food products, cosmetics, and small automotive parts.

For more information, contact: Jim Ahern, G+W Advanced Development and Engineering Center, 101 Chester Rd., Swarthmore, PA 19081, telephone (215) 544-7600. Circle 45

LITERATURE

The following is a listing, in brief, of some recent publications, marketing material, and technical literature we have read.

- Series of editorial reprints on robotics and CNC for education and training. Contact: Feedback, Inc., 620 Springfield Ave., Berkeley Heights, NJ 07922, telephone (201) 464-5181.
- Catalog of 1,400 government inventions. Contact: National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161, telephone (703) 487-4600.
- *Analog Dialogue*, a technical journal on circuits, systems, and software for real-world signal processing. Contact: Analog Devices, Rte. 1, Industrial Park, PO Box 280, Norwood, MA 02062.
- *The Robomatix Reporter*, an index of conference papers, news and journal articles, and special reports from both the private and the public sectors. Contact: EIC/Intelligence, Inc., 48 W. 38th St., New York, NY 10018, telephone (212) 944-8500.
- English edition of the Japanese publication *Robot News* to be published monthly as a translation of the two previous issues of the original. Contact: Antenna House, Inc., Sanyo Denko Bldg., 2F, 9-3, Niban-cho, Chiyoda-ku, Tokyo, 102 Japan, telephone 03 (234) 9631.
- Design guide of specifications and applications engineering information on digital motor/drives and microprocessor-based indexers. Contact: Compumotor Corp., 1179 N. McDowell Blvd., Petaluma, CA 94952, telephone (800) 358-9068 or, inside California, (707) 778-1244, collect.
- Catalog of pressure sensing switches for machine safety, warning signals, security alarms, door actuators, and traffic monitors. Contact: Hal Goetsch, Recora Co., PO Box 1220, Powis Rd., St. Charles, IL 60174, telephone (312) 584-3000.
- Report on machine vision systems for inspection, recognition, and control applications in manufacturing. Contact: Tech Tran Corp., 134 N. Washington St., Naperville, IL 60540, telephone (312) 369-9232.
- Brochure detailing seven data acquisition boards for the IBM PC. Contact: Data Translation, 100 Locke Dr., Marlboro, MA 01752, telephone (617) 481-3700.
- *Semioutlook*, a quarterly publication of semiconductor industry trends, analyses, and opinions. Contact: Semiconductor and Materials Institute, Inc., 625 Ellis St., Suite 212, Mountain View, CA 94043.
- *Artificial Intelligence & Robotics: Five Overviews* (Artificial Intelligence, Robotics, Expert Systems, Computer Vision, and Computer-Based Natural Language Processing). Contact: Business/Technology Books, 14 Evergreen Dr., PO Box 574, Orinda, CA 94563, telephone (415) 839-3370.